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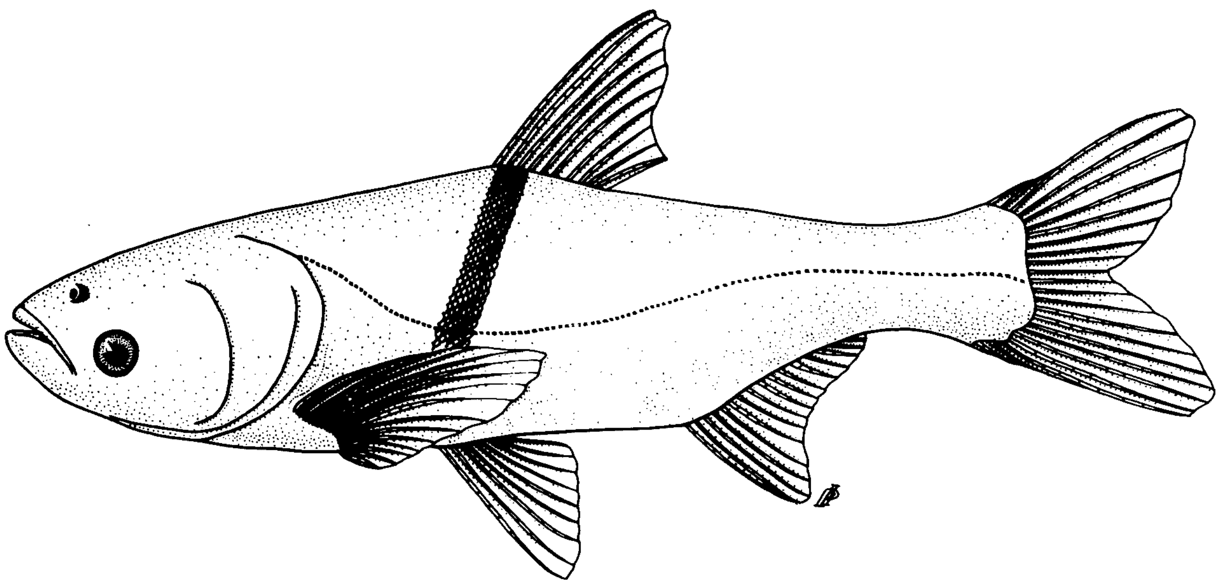
BIGHEAD CARP (*HYPOPHTHALMICHTHYS NOBILIS*): A BIOLOGICAL SYNOPSIS



Fish and Wildlife Service
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Biological Report

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Biological Report 88(29)
September 1988

Bighead Carp
(*Hypophthalmichthys nobilis*):
Biological Synopsis

by

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FAO Synopsis NMFS/5/151

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Acknowledgments

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Introduction

The bighead carp (*Hypophthalmichthys nobilis*) is recognized throughout the world, primarily because of its versatility in aquaculture operations. It is endemic to eastern China, and has been introduced worldwide as an important food fish. It also has been used in combination with other species of phytophagous fish to improve water quality and increase fish production, both in culture facilities and natural systems.

This summary of the available published literature on the biology and utility of this species follows the Food and Agricultural Organization of the United Nations (FAO) species synopsis format (Rosa 1965).

1. IDENTITY

1.1 *Nomenclature*

1.1.1 Valid Name

Hypophthalmichthys nobilis (Richardson 1845[1])

1.1.2 Objective synonymy

Leuciscus nobilis Richardson, 1845, Voy. Sulph. Ichthy., p. 140, pl. 63, fig. 3 (Canton).
Cephalus hypophthalmus Steindachner, 1866, Verh. Zool-bot. Ges. Wein 16:383, pl. 4 (Hong Kong).
Hypophthalmichthys mandschuricus Kner, 1867, Novara, Fische 1:350 (Shanghai).
Hypophthalmichthys simoni Bleeker, 1879, Verh. Akad. Amsterdam 18:1 (Yangtze Kiang).

1.2 *Taxonomy*

1.2.2 Affinities

– Suprageneric (Nelson 1984)
Phylum Chordata
Subphylum Vertebrata (Craniata)
Superclass Gnathostomata
Grade Pisces
Subgrade Teleostomi
Class Osteichthyes
Subclass Actinopterygii
Infraclass Neopterygii
Division Halecostomi
Subdivision Teleostei
Superorder Ostariophysi
Series Otophysi
Family Cyprinidae
Order Cypriniformes
Suborder Cyprinoidei
Subfamily Hypophthalmichthyinae

[1] At least one author (Lin 1934) erroneously cited the valid name from Richardson (1844).

– Generic

Hypophthalmichthys Bleeker, 1860. Ichth. Arch. Ind. Prodr. II, Cypr., p. 283, 405.

Diagnostic characters (Lin 1934): Oblong, compressed. Head moderate; snout bluntly rounded; mouth small, terminal, somewhat oblique; lower jaw slightly longer. Premaxillary little protractile. Lips thin, no labial fold. Postlabial groove very shallow and restricted to corners of mouth. Mandibular shaft not extended to beyond lip, with rather sharp edge. Barbels absent. Eye small, positioned below the level of angle of mouth. Suprabranchial organ present. No pseudobranchiae. Gill membranes broadly joined across the isthmus. Scales small, lateral line complete. Dorsal fin without osseous spine and with less than 9 branched rays, dorsal origin behind pelvic fin insertion. Anal fin moderate, with more than 10 branched rays. Pharyngeal teeth in 1 row, 4-4, sole-shaped, masticatory surface strongly striated. Vent immediately before anal fin origin. Intestine long, convoluted.

– Specific (Lin 1934)

Hypophthalamichthys nobilis (Richardson)
Type specimen:*Leuciscus nobilis* Richardson, 1845, Voy. Sulph. Ichthy., p. 140, pl. 63 fig. 3 (Canton).
Type locality: Very common in rivers and lakes of China and also one of the common fishes cultivated in ponds.
Recorded distribution: Kiangsu; Hupeh to Kwangtung and Formosa.
Diagnostic characters: Dorsal fin 3/7 (soft, unbranched rays/soft, branched, articulated rays); anal fin 3/12; lateral line about 100. Depth 3.7; head 2.8 in. length. Eye 8 in. head; snout 3; postorbital distance 1.6; interorbital 2.3; width of head 2; pectoral 1.7; longest dorsal ray 1.8; ventral 2.3; anal 3; maxillary 3.7; depth of peduncle 3.3. Abdominal keel not extending anterior of pelvic fins. Dorsal fin origin nearer base of caudal fin than tip of snout. Intestine long with many convolutions.
Subjective synonymy: *Aristichthys nobilis* Oshima, 1919. Ann. Carnegie Mus. 12(2–4): 169–328.

1.2.2 Taxonomic status

There are taxonomic ambiguities in the literature concerning the genus of this species. According to Howes (1981), the genus *Hypophthalmichthys* contains three nominal species: *H. nobilis* (Richardson), *H. molitrix* (Val.), and *H. harmandi* Sauvage.

Oshima (1919) established the genus *Aristichthys* to contain *nobilis* on the basis that differences in gill raker form, abdominal keel position, and pharyngeal dentition between *nobilis* and *molitrix* were significant enough for generic rank ("Gill rakers slender and long, set very closely, with many membranous septa.

Postventral abdominal keel. Pharyngeal teeth, 4-4, very high, strongly compressed laterally, inner surface with a large oval concavity"). Gosline (1978) maintained a tri-lobed swimbladder as evidence of "clear indications of a cultrin deviation of *Hypophthalmichthys* and *Aristichthys*." Howes (1981), however, disagreed with these authors, and stated that taxa *nobilis* and *molitrix* "possess unique synamorphies, and consequently belong to *Hypophthalmichthys*."

Hypophthalmichthys nobilis is the name chosen by the American Fisheries Society's Committee on Names of Fishes, and for this reason, it is the name used in this synopsis (Robins et al. 1989).

There also is some uncertainty about the subfamily classification for this species. Hypophthalmichthinae was recognized by Gill (1893), based on a category Hypophthalmichthina introduced by Gunther (1868) to contain the genus *Hypophthalmichthys* (Howes 1981). Kryzanovskij (1947) suggested *Hypophthalmichthys* be placed in the subfamily Leuciscinae, along with the genus *Ctenopharyngodon*, and most of the other cyprinids, based on ontogenetic development. Howes (1981) disagreed with this, and presented evidence to show that *Ctenopharyngodon* and *Hypophthalmichthys* represent separate lineages of diphyletic Cyprinidae. After analyzing 22 character complexes, Howes (1981) suggested that *Ctenopharyngodon* "forms part of a monophyletic assembly termed the squaliobarbine group and *Hypophthalmichthys* is identified as the most derived member of the abramine group." The phylogenetic relationships separating the two are discussed in section 1.3.2.

1.2.3 Subspecies

No subspecies are recognized within *Hypophthalmichthys nobilis*.

1.2.4 Standard common names; vernacular names

English common names for *H. nobilis* used most often are bighead carp and bighead; other common and vernacular names are given in Table 1.

1.3 *Morphology*

1.3.1 External morphology

The general shape of the bighead carp (Figure 1) is characterized as deep-bodied and moderately compressed laterally (Henderson 1976). It has no spines in the fins. The scales are cycloid and very small. Its coloration is dark gray above and off-white below with dark gray to black irregularly shaped and positioned splotches over the entire body. This pattern begins to show when the fish is about 8 weeks old. The head and mouth of the bighead carp are disproportionately large. The premaxillary and protruding mandible form rigid bony lips and the terminal mouth is not expandable. The eyes are located anteriorly on the head and have a definite ventral positioning. A smooth keel is between the base of the caudal fin and the pelvic fins.

Berry and Low (1970) described the following morphometric and meristic characteristics for 20 bighead specimens (12.2–18.2 cm):

1.3.2 Anatomy

Body: Broad, moderately compressed; mean breadth/SL = 0.29.

Profile: Ventral more convex than dorsal. Abdominal keel prominent.

Head: Broad; mean length/SL = 0.36; mean width/SL = 0.17.

Snout: Slightly depressed and moderately long; mean length/SL = 0.10.

Mouth: Dorsal, lower jaw longer than upper.

Interorbital: Broad; mean width/SL = 0.16.

Caudal peduncle: Moderately long; mean length/SL = 0.20; mean height/SL = 0.11.

Scales: Cycloid, oblong, very small; margins entire; focus central.

Dorsal fin: 2/8; rounded, origin behind ventrals and nearer to base of caudal than to tip of snout.

Pectoral fin: 1/17–19; Reaches beyond ventral origin.

Ventral fin: 1/8–9.

Anal fin: 2/12–14; rounded.

Caudal fin: 5–6/17/4–7 (unbranched rays/branched rays/unbranched rays).

Lateral line: 98–100 scales along lateral line; 26–28 scales above lateral line; 16–19 scales below lateral line. Complete, markedly ventrally convex, running along middle of caudal peduncle.

Howes (1981) presented an extensive description of the comparative osteology of the genus *Hypophthalmichthys*, into which he grouped both the silver and bighead carps. He examined 22 charac- teristics in detail and used them to evaluate the monophyletic lineage of *Ctenopharyngodon* and *Hypophthalmichthys.*

Phylogenetic relationships of *Hypophthalmichthys* that were identified as different from those of *Ctenopharyngodon* follow:

1. Medial ethmoid notch floored by vomer.
2. Frontal with an acute lateral slope, providing an extensive cranial dilatator fossa.
3. Extensive lateral occipital fenestra.
4. Modification of the adductor hyomandibulae muscle involving partial attachment to the preoperculum and upper pharyngeal tissue.
5. Expanded horizontal cleithral lamina.
6. Markedly rounded epibranchials.
7. Deep basioccipital keel with marked concave anterior border.
8. Carotid foramen contained in vertically produced parasphenoid process.

Table 1. *Standard common and vernacular names.*

Country	Standard common name	Vernacular name	Reference
China	Twa Tow	Twa Tow	Birtwistle 1931
	Yung-yu	Yung-yu	Roberts et al. 1973
		Yung Ue (Cantonese)	Lin 1934
			Chen 1934; Lin 1934
		Sung Ue (Cantonese)	Lin 1934
		Taai Tau Ue (Cantonese)	Lin 1934
		Pun Tau Ue (Cantonese)	Lin 1934
		Hak Lin Ue (Cantonese)	Birtwistle 1931
		Tye Tow Uve (Cantonese)	Birtwistle 1931
Czechoslovakia	Tolstolobik pestry	Tolstolobik pestry	Blanc et al. 1971
Germany	Marmokarpfen	Marmokarpfen	Bremer 1980
	Geflecter silberkarpfen	Geflecter silberkarpfen	Molnar 1969;
			Fuhrmann 1980;
			Leider 1981
Hungary	Pettyes busa	Pettyes busa	Blanc et al. 1971
Poland	Tolpyga pstra	Tolpyga pstra	Blanc et al. 1971
	Tolpygi pestrej	Tolpygi pstrej	Krzywosz et al. 1977
Romania	Crap-argintiu-patat	Crap-argintiu-patat	Blanc et al. 1971
Soviet Union	Piostryi Tolstolobik	Piostryi Tolstolobik	Blanc et al. 1971
United States	Bighead carp	Bighead carp	Robins et al. 1988

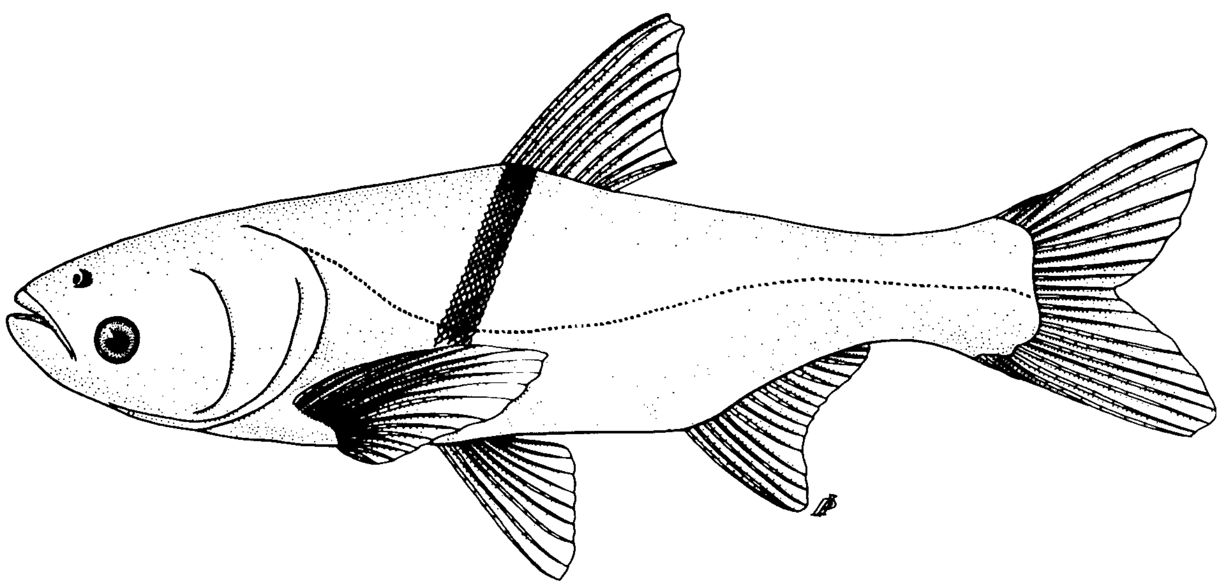

Figure 1. *Hypophthalmichthys nobilis* (Richardson 1845).

9. Lateral ethmoid - frontal fenestra.
10. Expanded 1st and 4th epibranchials. The 5th present and hypertrophied.
11. Extensive fossa in pharyngeal bone.
12. Exoccipital wing extended distally to contact pterotic spine.
13. Curved post-temporal.
14. Pterosphenoid contributing to anterior trigimino - facialis foramen.
15. Cardiform masticatory plate with tubular posterior extension.
16. Intercalar invading border of exoccipital.
17. Complexly developed epibranchial organ.
18. Neural complex bifurcated and articulating with supraoccipital.

Berry and Low (1970) present a detailed description of the internal anatomy of bighead carp (12.2 to 18.2 cm SL). The jaws are small, with delicate symmetrical arches perforated by pits along their entire length. There is one row of weakly developed pharyngeal teeth, four on the left and four on the right, arranged uniserially. These teeth bite against a horny pad or molar that is soft, with slight patterns on the free surface.

Gill rakers are long and closely arranged, situated vertically in relation to the gill filaments, thus forming a reticulum for filtering fine food particles. Voropaev (1971) found that the filter feeding "mesh size" in the bighead carp increased from 20 to 60 μm with an increase in weight from 20 to 2,000 g. Fang (1928) reported the presence of both narrow and broad gill rakers in the bighead carp; however, Berry and Low (1970) found only narrow gill rakers, all of fairly uniform width. Henderson (1976) reported that gill filaments are spaced 75 to 100 μm apart at their point of attachment to the gill arch. As they extend outward they widen and overlap and thus have no spaces between them. Cremer and Smitherman (1980) described the gill rakers of bighead carp as closely set but separate from one another. In 22-cm fish the mean gill raker length and width measured 3,230 μm and 85 μm. Berry and Low (1970) recorded the following measurements of gill rakers and filaments from 20 bighead specimens (12.2 to 18.2 cm SL):

Gill Rakers	Total length (mm)
branchial arch	15.00
branchial arch	24.52
branchial arch	33.64
branchial arch	43.43
branchial arch	52.39
Gill filaments	5.12

The alimentary tract is differentiated into a short, cylindrical esophagus, a pyloric sphincter, and intestinal swelling, intestine proper, and rectum (Berry and Low 1970). The intestine proper is long and narrow and the esophagus is situated nearly vertically just before the anterior chamber of the swim bladder (Berry and Low 1970). Coiling of the alimentary canal follows a constant pattern. The entire digestive tract is 3.17–5.01 times the body length (Dah-Shu 1957). The liver is situated on the dorsal surface of the gut and the lobes usually extend the entire length of the abdominal cavity. In close association with the liver is a diffuse pancreas, from which small ducts enter the bile duct, forming the hepatopancreatic duct. A large gall bladder lies between the liver and intestine, and the dark red spleen is narrow and separated into two or three parts. The swim bladder lies between the gut and the kidneys. It is hollow and enclosed by thick connective tissue, and divided into two chambers. The anterior chamber is bulbous and oval; the tapering posterior chamber is reduced to half the size of the anterior chamber. Gonads of immature specimens occur as paired, delicate white strips vertical to the swim bladder, closely adhering to the abdominal cavity membrane.

1.3.3 Histology

A detailed account of the gut histology was presented by Berry and Low (1970). The esophagus is initially surrounded by a thin layer of serosa, and then a thick muscularis, that consists of an outer part of striated circular muscles and an inner one of striated longitudinal to oblique muscles. There are relatively few shallow folds in the mucosal layers of the esophagus. A pneumatic duct enters the middle region of the esophagus on the dorsal side. It is encircled by an outer layer of serosa, followed by a layer of striated longitudinal muscles, then a layer of fibrous connective tissue, and finally by a layer of cuboidal epithelial cells that line the lumen. The intestinal swelling is covered with a thin layer of serosa, but the muscularis layer is reduced. There is a thin layer of smooth longitudinal muscles and a thicker layer of smooth circular muscles. Because a mucosal layer is lacking, the submucosa is in direct contact with the gut lumen.

The intestine proper is smaller in diameter than the esophagus or intestinal swelling and has fewer mucosal folds. The submucosa extends through the apex of the mucosal folds into the lumen of the intestine. As the intestinal swelling merges with the intestine proper, epithelial cells in the submucosa become abundant. Lymphocytes and granular cells are also very prominent on the submucosa. The rectum is surrounded by serosa, outer longitudinal and inner circular muscles. The epithelium consists mainly of goblet cells. The submucosal layer is thick and vascularized, containing numerous granular cells and lymphocytes.

1.3.4 Cytomorphology

The modal diploid (2n) chromosome number in bighead carp is 48 (Bozhko et al. 1976; Vasil'ev et al. 1978;

Marian and Krasznai 1979; Beck et al. 1980; Zan and Song 1980), and all chromosomes in the karyotype have a homologous pair. Marian and Krasznai (1979) described the karyotype as having 84 chromosome arms with 20 metacentric, 16 submetacentric, and 12 telocentric chromosomes. Chromosome length varied from 1.8 to 4.98 μm; the total length of the chromosome set was equal to 73.9 μm.

Vasil'ev et al. (1978) found 74 chromosome arms in the bighead, as well as 26 metacentric and submetacentric, 20 subtelocentric, and 2 acrocentric chromosomes.

Zan and Song (1980) described 14 metacentric, 24 submetacentric, and 10 acrocentric chromosomes, including 1 pair with a secondary constriction on the long arms. Beck et al. (1980) found 18 metacentric, 30 submetacentric, and no telocentric chromosomes. They explained that these differences may be due to excessive chromosomal contraction caused by overexposure to colchicine, which would obscure the short arms of the small submetacentric chromosome.

1.3.5 Hematology

Molnar (1969) and Molnar and Tamassy (1970), who investigated the hematology of the bighead carp, recorded the following data: 1.68 × 104 leukocytes/mm^3; 8.7 g/100 mL hemoglobin; and hematocrit 40%. The blood (pH 7.0) also was found to contain 44 mg/100 mL phosphorus (P); 10.1 mg/100 mL calcium (Ca); and 400 mg/100 mL sodium (Na). The hemoglobin content of a single erythrocyte, which the authors termed the "M index," was 5.26 × 106.

1.3.6 Protein specificity

Beck et al. (1983) performed electrophoretic analysis on eight protein systems in *Ctenopharyngodon idella* (grass carp), *H. nobilis*, and their F1 triploid hybrid. Plasma and red cell hemolysate and liver supernatant were subjected to vertical slab polyacrylamide gel electrophoresis, to analyze lactate dehydrogenase (LDH), liver esterases (EST), superoxide dismutase (SOD), hemoglobin, 6-phosphogluconate dehydrogenase (6PGDH), glucose-6 phospate dehydrogenase (G6PDH), isocitrate dehydrogenase (IDH) and transferrin (TRF). The LDH phenotypes of *C. idella* and *H. nobilis* were distinctly different. Isoelectric focusing yielded the following isoelectric points for given LDH isozymes of *H. nobilis*:

Isozyme	Isoelectric points
A4	6.9
A3B1	6.1
A2B2	5.5
A1B3	5.0
B4	4.6
C4 (liver specific)	9.6

Gels containing liver homogenates of *H. nobilis* had two zones of EST activity. The bighead carp also was monomorphic for a single SOD band; however, since three phenotypes were found in liver homogenates from triploid hybrids of *C. idella* × *H. nobilis*, it may be assumed that polymorphism exists at the SOD locus in either one or both parental species. The hemoglobin of *H. nobilis* consisted of four weakly stained fractions and one prominent major fraction. The IDH, G6PDH, and 6PGDH enzymes each were resolved as a single invariant band, and each was assumed to be encoded by a single genetic locus. Two electrophoretically distinguishable TRF zones were detected in plasma from *H. nobilis*. Each zone was composed of two closely spaced bands. Three TRF phenotypes also were found in *H. nobilis*. This variation is attributed to two alleles segregating at a single locus. Homozygous individuals possessed two closely spaced TRF bands, whereas heterozygotes had four TRF bands.

1.3.7 Other body consitituents

Shimma and Shimma (1969) investigated the fatty acid composition of lipids extracted from several tissues of cultured bighead carp. Lipid content of dorsal flesh ranged from 1.4% to 1.5% and cholesterol content varied from 87 to 108 mg/100 g of tissue. Lipid content of the hepatopancreas ranged from 5.5% to 9.35%, and the cholesterol content ranged from 512 to 1,226 mg/100 g of tissue. Major components of the fatty acid composition of the dorsal flesh and hepatopancreas were 16:0, 16:1, 18:0, 18:1, 20:5, and 22:6 acids. The fatty acid composition was similar in liver and muscle tissue of bighead carp raised on natural and artificial feed (Csengeri et al. 1978).

Kirilenko and Yermolayev (1976), who studied the forms of high-energy compounds in the muscle of bighead carp, recorded the following data (units expressed as micro-moles of Adenine per gram of wet tissue):

Adenosine triphospate = 0.57 ± 0.09;
Adenosine diphosphate = 0.74 ± 0.03;
Adenosine monophosphate = 2.35 ± 0.06.

2. DISTRIBUTION

2.1 *Total Area*

2.1.1 Native range

The bighead carp is endemic to eastern China, (Figure 2) in the lowland rivers of the north China plain and South China, including the Huai (Huai Ho), Yangtze, Pearl, West (Si Kiang), Han Chiang and Min rivers (Herre 1934; Mori 1936; Chang 1966; Chunsheng et al. 1980). The mean annual air temperature ranges from –4 °C in the Manchurian Plain Region to 24 °C in the South (Hseih 1973). Air temperature extremes are –30 °C to 16 °C during the coolest month (January), and

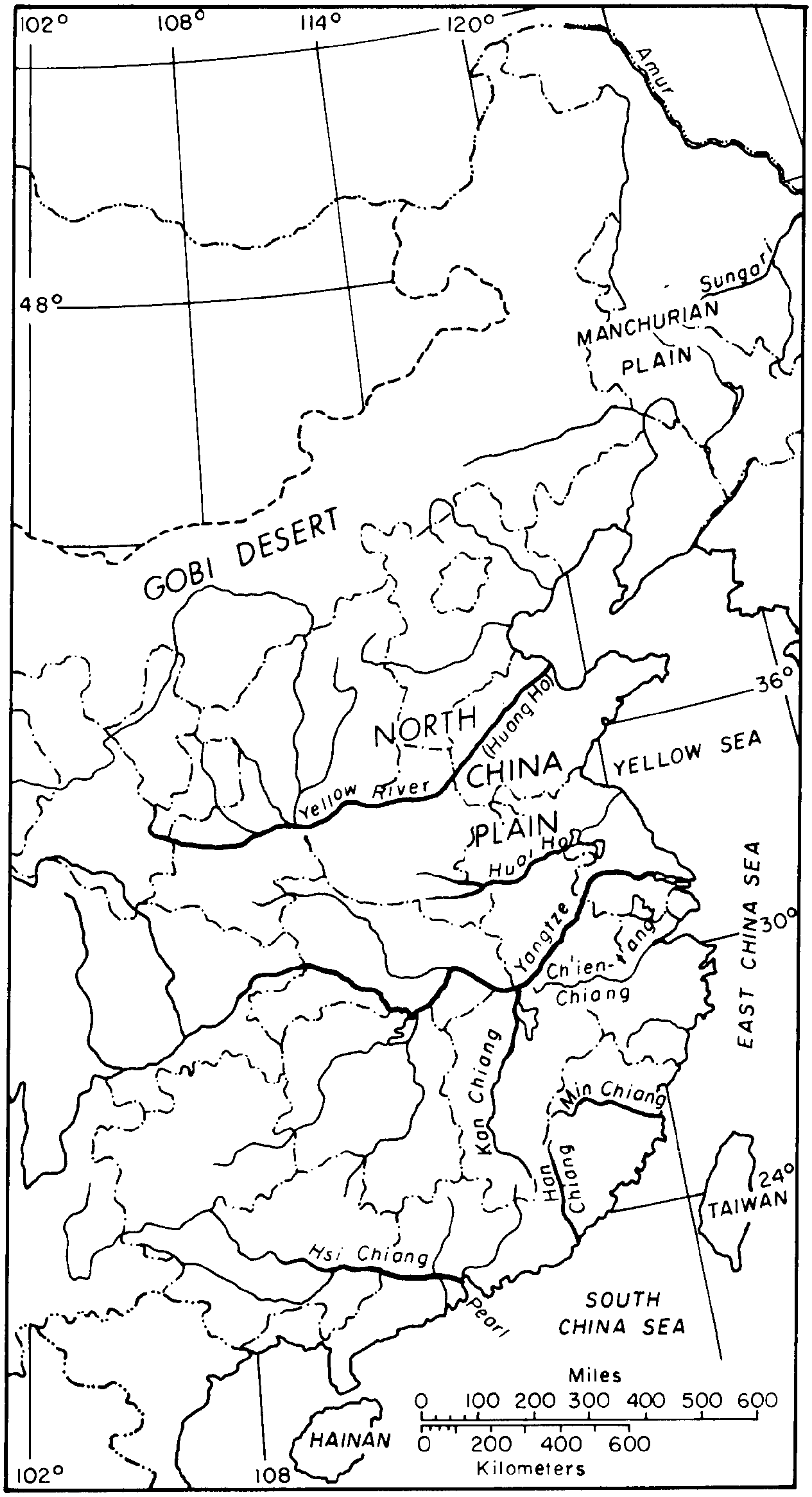

Figure 2. Native distribution of the bighead carp (redrawn from Hseih 1973).

between 20 °C and 30 °C during the warmest month (July). Annual precipitation is greatest during the summer monsoon period between May and October, when more than 80% of the annual rainfall occurs. Average annual precipitation is 500–1,000 mm in the Manchurian Region, 500–700 mm in the North China plain, and 1,500–2,000 mm in the tropical and subtropical zones of South China. In the Manchurian region, river levels are lowest during July and highest in August, coinciding with the rainy season. The rivers are frozen for 4 to 6 mo per year—generally from late October or early November until March. Melting ice and snow cause floods in spring; however, most floods result from clogging by ice floes rather than from the larger volume of water. The lowest water level of rivers in the north China plain is generally in May and June. Water level increases in spring from the melting snow, and is highest in August. Most floods are caused by summer monsoon rains. In south China, water levels and floods are highest during the monsoon season. The annual discharge of the major rivers of China is given in Table 2 and precipitation and runoff in several major river basins are given in Table 3.

2.1.2 Introductions

The bighead carp has been promoted for use in aquaculture in at least 32 countries worldwide (Table 4). It was introduced into the Soviet Union from China in 1949 (Bardach et al. 1972), and is now being used for production and water quality improvement in many natural waters and water storage lakes, including the Volga delta, the Kuban system, the Karakum Canal, and the Kuibyshev, Tsymlansk and Novosibirsk reservoirs. Bighead carp have been successfully acclimatized in waters at a latitude of 45° N and further south. In reservoirs of the temperate zone north of this latitude, the commercial catch is small or nonexistent. Natural reproduction of bighead carp in the Soviet Union has been documented in the Karakum canal (Aliev 1979) and the Syr-Dar'ya River (Verigin et al. 1978), and self-sustaining populations have been reported in the basins of the Amudarya and Kuban rivers (Aliev 1965; Anon. 1970).

Welcomme (1981) reported that the bighead carp is established in the Danube River of Europe. It is widespread in the river basin and supports a sport fishery.

Table 2. *Annual discharge of the major rivers of China (from Tapiador et al. 1977).*

River	Annual flow (billions of m^3/yr)	Drainage area (millions of km^2)	Annual flow (thousands of m^3/km^2)
Hai	15	0.26	58
Yellow	48	0.75	64
Hwai	42	0.26	162
Yangtze	1,020	1.8	567
Pearl	356	0.42	848

Table 3. *Precipitation and runoff in several of China's major riverbasins (from Tapiador et al. 1977).*

River system	Basin area (km^2)	Mean annual precipitation (mm)	Mean annual runoff (mm)	Mean annual evaporation (mm)	Runoff coefficient (%)
Sungari	523,580	512	141	371	27.6
Yellow	724,100	415	65	350	15.7
Hwai	164,560	840	198	642	23.6
Yangtze	1,808,500	1,050	568	482	50.1
Chientang	49,930	1,650	940	710	57.0
Min	60,800	1,710	1,074	636	62.8
Han	29,700	1,655	982	673	59.0
Pearl	437,230	1,480	890	590	60.2

Table 4. *Introductions of bighead carp.*

Country	Origin	Date	Purpose	Reference
Brazil	China	1979	Assessment for culture	Welcomme 1981
Bulgaria	–	1964	Culture	Krupauer 1971; Anon. 1974
Costa Rica	Taiwan	1976	Culture	Welcomme 1981
Cuba	–	–	–	Welcomme 1981
Czechoslovakia	Hungary	1963	Inadvertent	Holcick and Geczo 1973
England	Austria	1975	Inadvertent	Stott and Buckley 1978
Figi	Malaysia	1968	Culture/ weed control	Mastrarrigo 1971
Germany FR.	Hungary	1964	Culture	Welcomme 1981
Hong Kong	–	–	–	Chaudhuri 1968; Man and Hodgkiss 1977
Hungary	China Soviet Union	1963–1964 1968	Culture	Molnar 1979 Pinter 1980
India	–	–	Culture	Alikunhi et al. 1963; Tubb 1966
Indonesia	Japan	1964	Culture	Welcomme 1981
Israel	Germany	1972 1973	Culture Culture	Rothbard 1981 Tal and Ziv 1978
Japan	China	1915–1945	Culture	Kuronuma 1954
Korea	Taiwan	1963	Culture	Welcomme 1981
Laos	Japan	1968	Culture	Chanthepha 1969
Maylaysia	China	1800's	Culture	Welcomme 1981
Mexico	Cuba	1975	Culture	Welcomme 1981
Nepal	Hungary	1972	Culture	Anon. 1973
Panama	Taiwan	1978	Culture	Welcomme 1981
Peru	Israel	1979	Culture	Welcomme 1981
Philippines	Taiwan	1968	Culture	Welcomme 1981
Poland	Soviet Union	1964	Culture	Opuszynski 1979
Rumania	–	1959	Culture	Chanthepha 1969; Huet 1970
Singapore	–	–	Culture	Tubb 1966
Taiwan	China	–	Culture	Tang 1960

Table 4. *Continued.*

Country	Origin	Date	Purpose	Reference
Thailand	China	1913	Culture	Welcomme 1981; Chaudhuri 1968
Turkey	Rumania	1972	Culture	Anon. 1973
United States	Taiwan	1972	Culture/ research	Henderson 1979; Cremer and Smitherman 1980
Soviet Union	China	1949 +	Culture/ water quality improvement	Bardach et al. 1972; Huet 1970
Vietnam	China	–	Culture	Chaudhuri 1968; Welcomme 1981
Yugoslavia	Rumania, Hungary, Soviet Union	1963 +	Culture	Welcomme 1981

Japan imported bighead carp fry from Shanghai between 1915 and 1945 (Kuronuma 1954). In 1930, young bighead carp were identified in the River Tone, and later in Lake Kasumi. The bighead carp is believed to be established in these waters (Tsuchiya 1979).

In the Philippines, the bighead carp reportedly reproduces in the Pampanga River (Datingaling 1976); however, there is no record of its permanent establishment there.

Tang (1960) collected bighead carp fry from the Ah Kung Tian Reservoir in Taiwan, suggesting natural reproduction; however, this incident could have been caused by unusual hydrological and climatic conditions.

Bighead carp have been introduced into several countries in central and eastern Europe (Table 4). In these countries it is used for food production and water quality control (Krupauer 1971).

Bighead carp were introduced into England with a consignment of grass carp imported from Austria in 1975, which was found to contain both bighead and silver carp (*H. molitrix*). These species are being studied for use in cultivation and nutrient removal from eutrophic waters in the United Kingdom (Krupauer 1971; Stott and Buckley 1978).

Bighead carp also were introduced inadvertently into Hungary in 1963, mixed with a purchase of grass carp and silver carp. Since 1964, this species has been intentionally introduced from the Soviet Union. It is now the most popular fish used in pond farming practice and the second most important fish species (after the common carp, *Cyprinus carpio*) in Hungarian fish farming (Pinter 1980).

The bighead carp was first introduced into the United States in 1972 (Henderson 1979). It was brought into Arkansas by a private fish farmer in an attempt to improve water quality in fish production ponds (Henderson 1976, 1978, 1983). In 1974, the Arkansas Game and Fish Commission began evaluating the bighead carp and other Chinese carps to determine their potential impact on the environment and to assess their beneficial characteristics. Restrictions were enforced to prevent the fish from being stocked into public waters from private sources, and methods to control accidental populations were investigated (Henderson 1975; Marking and Bills 1981). Fisheries personnel from Auburn University, AL, also obtained stocks of bighead carp in 1974 to assess their potential in polyculture systems with existing cultured species in the United States (Cremer and Smitherman 1980).

There are records of bighead carp from open waters in the United States. In 1981, a single specimen was caught in the Ohio River at mile marker 919, below the Smithland Dam, Kentucky (Freeze and Henderson 1982); it was assumed that the fish escaped from an aquaculture facility. Other reports include one adult from Chain Lake, Schuzler County, IL, in September 1986, and two adults from the Mississippi River in Illinois—one at mile marker 364 in Hancock County, December 1986, and the other 4.5 miles NNW of Gadstone in Henderson County in January 1987.

2.2 *Differential Distribution*

2.2.1 Eggs, larvae, and juveniles

The spawn of bighead carp is generally deposited among the rocks of rapids (Breder and Rosen 1966) in river channels, behind sandbars, and at islands at the junction of currents. The eggs are bathypelagic and must float to hatch. In rivers of eastern Asia, if spawning occurs during periods of rising water level, the eggs and larvae are carried downstream by the current to quiet, flooded lakes, creeks, and channels, which serve as nursery areas (Nikolsky 1963). If eggs and larvae descend during periods of falling water, the larvae actively migrate to nursery areas, out of the main channel, to seek refuge in vegetation. Juveniles may migrate from the nursery areas up and down the main river channel.

2.2.2 Adults

Adults remain in the river channel until the water level rises. They then migrate upstream to the spawning grounds, which are characterized by rapidly flowing water. After spawning, they migrate to floodland lakes (Nikolsky 1963; Chang 1966).

2.3 *Determinants of Distribution Change*

2.3.1 Reproduction

Although the bighead carp is promoted worldwide for use in aquaculture, it has not readily become established outside its native range, except in the Soviet Union, Japan, and Europe (Anon. 1970; Aliev 1979; Tsuchiya 1979; Welcomme 1981), primarily because of its strict reproductive requirements (section 3).

2.3.2 Temperature

Bettoli et al. (1985) reported the preferred temperature range of bighead carp in a laboratory gradient as 25.0 °–26.9 °C, and the critical thermal maximum temperature as 38.8 °C. No information was found on the lower lethal temperature of bighead carp; however, considering their native range in China, they are able to tolerate extremes in water temperature, from temperate to tropical. Stott and Buckley (1978) reported that the bighead carp seemed less resistant than the silver carp to cold, during growth studies of the two species in the United Kingdom. Negonovskaya (1980) recorded the following temperatures for feeding activity of bighead carp in small lakes in the Soviet Union:

Most active: 20 ° to 22 °C
50% decrease: 12 °C
Near cessation: 10 °C
Reaction to outer stimuli ceases: 5 °C

Ling (1977) found that the optimum temperature for feeding activity in China is 20° to 30° C. Activity is greatly reduced at less than 15° C and is near cessation at less than 10° C.

In general, optimum temperature for reproduction is between 22 ° and 25.5 °C (Vovk 1979). Temperature has been recorded during the spawning season in several China rivers (Chang 1966). In the Yangtze River, spawning occurred when the water temperature reached 26 ° to 30 °C. In the West River, temperatures were 25 ° to 30 °C and at the E-Chong spawning grounds, temperatures were recorded between 21 ° and 23.5 °C during the time the bighead carp spawns. In the Han River, spawning occurred at a water temperature near 18 °C (Chunsheng et al. 1980). Verigin et al. (1978) observed eggs and larvae of bighead carp in the Syr-Dar'ya River, Soviet Union, when water temperature was above 22 °C.

2.3.3 Oxygen

Negonovskaya and Rudenko (1974) found that the lethal oxygen content for juvenile bighead carp, at an average weight of 73 mg, was 0.33 mg/L. In younger and smaller bighead carp (average weight 23 mg) the oxygen threshold was higher, 0.40 mg/L. Chen and Shih (1955) found that the oxygen consumption of bighead carp decreased with an increase in age and body weight, and that it was directly proportional to water temperature. They reported that the rate of oxygen consumption of bighead carp during winter was only 1/6 of the rate during summer.

2.3.4 Salinity

Chervinski (1980) conducted research on the salinity tolerance of bighead carp, however, the results of the study indicating salinity concentrations used, were unclear.

2.4 *Hybridization*

2.4.1 Hybridization in fish culture

The bighead carp has been successfully hybridized with grass carp, common carp and silver carp by using induced spawning techniques (section 7.3). Most research has been done on the production of a hybrid from a cross of female grass carp with male bighead carp (Makeeva and Sukanova 1966; Andriasheva 1968; Makeyeva 1972; Marian and Krasznai 1978). The first successful grass carp × bighead carp hybrid was produced in the Soviet Union in 1963 (Vinogradov 1968), in Hungary in 1975 (Marian and Krasznai 1978), and in the United States in 1979 (Sutton et al. 1981). Its utility as a sterile, biological weed control agent has been studied, in an attempt to mitigate the controversy surrounding its potential for establishment in open waters. Characteristics of the hybrid that are similar to the grass carp parent include the elongated body, size of the head, position of the eyes, and the terminal mouth.

Intermediate characteristics are the dorsal–ventral profile, size and shape of scales, number of scales in the lateral line, length of gill rakers, size of mouth, size of caudal fin, and insertion of the dorsal fin in relation to the ventral fin (Berry and Low 1970; Sutton et al. 1981). The hybrid also has an abdominal keel similar to that in the bighead carp and the length and height of the caudal peduncle resembles the bighead carp parent (Berry and Low 1970). Morphometric characteristics for 10 individuals of the grass carp, bighead carp, and their hybrid are given in Table 5 (Sutton et al. 1981). Kilambi and Zdinak (1981) gave a detailed comparison of early developmental stages, and morphological and meristic characteristics of this hybrid.

Much work has also been done on the karyology of the hybrid produced by crossing the female grass carp with the male bighead carp. Marian and Krasznai (1978) found that the diploid (2n) chromosome number was 72, with 30 metacentric, 24 to 26 submetacentric, and 18 telocentric chromosomes. Beck et al. (1980) also found 72 chromosomes for the hybrid karyotype, yet described 29 metacentric and 33 submetacentric chromosomes. They suggested that to obtain this triploid hybrid, the male parent contributes a haploid and the female a diploid chromosomal complement. The hybrid thus receives 9 metacentric and 15 submetracentric chromosomes from *H. nobilis*, and 30 metacentric and 18 submetacentric chromosomes from *Ctenopharyngodon idella*.

The reciprocal cross (bighead female × grass carp male) has also been produced (Andriasheva 1968; Makeyeva 1972; Verigin et al. 1975). Embryonic and larval developmental characteristics were described by Makeeva (1972). External characteristics of the hybrid were discussed by Verigin et al. (1975); of 20 characteristics observed, 13 resembled the grass carp parent and 6 the bighead carp parent.

Successful artificial crosses also have been made with the bighead carp and common carp. Development of a hybrid resulting from female common carp × male bighead carp was discussed by Makeyeva (1968; 1972) and Verigin and Makeeva (1972). It characteristically has 23 to 26 myotomes in the trunk and 15 to 17 in the tail. The diploid set of chromosomes in the hybrid is 74 to 75 (Vasi'lev et al. 1978). The position of the mouth is terminal, resembling the bighead parent.

Makeyeva (1972) produced a reciprocal cross of female bighead carp with male common carp. Most of the embryonic and larval development of this hybrid resembled the carp, showing characteristics such as a distended yolk sac and a similar number of myotomes in the trunk (23 to 24). A few embryos resembled the bighead parent, probably as a result of gynogenetic development.

Table 5. *Morphometric characteristics for grass carp x bighead carp hybrids and parents. Values in percent of standard length (Sutton et al. 1981).*

Characters	*C. idella*	Hybrid	*H. nobilis*
Length of head	27.2 (26.5–27.9)	28.8 (27.8–29.7)	36.4 (35.2–38.0)
Length of snout	9.56 (9.0–10.1)	10.4 (9.9–11.1)	12.1 (11.9–12.0)
Length of orbit	5.03 (4.5–5.8)	5.7 (4.7–6.3)	7.0 (6.4–7.5)
Interorbital width	14.5 (13.8–15.2)	13.9 (12.5–14.5)	18.5 (17.5–19.1)
Predorsal fin	53.6 (51.6–55.5)	53.1 (51.5–54.)	55.8 (53.3–57.8)
Preanal length	79.4 (76.4–82.3)	76.3 (73.6–82.9)	72.8 (71.3–75.2)
Depth of body	22.4 (20.2–23.4)	25.8 (24.2–27.7)	32 (29.8–34.2)
Depth of caudal peduncle	12.4 (11.2–13.0)	11.6 (10.9–12.0)	11.8 (11.1–12.1)

Hybrids of bighead carp and silver carp or the reciprocal have been produced in China (Zhongying et al. 1979), the Soviet Union (Andriasheva 1968; Grozev 1977), Taiwan (Tang 1965), and the United States (Green and Smitherman 1984). Studies in the Soviet Union indicated that the survival of larvae was higher, and the viability of fingerlings greater than in hybrids resulting from crosses of other phytophagous fishes (Andriasheva 1968). Mortality was recorded as 11.3% for bighead carp × silver carp hybrids and 18.5% for the reciprocal. In structure and number of gill rakers, the hybrid was intermediate between the bighead carp and silver carp. Green and Smitherman (1984) compared growth and survival of fry and fingerling bighead carp, silver carp, and their reciprocal hybrids. At a stocking rate of 98,800 fish/ha, the yield of the bighead carp × silver carp was greater than that of the reciprocal hybrid, and survival was 73% and 70%, respectively. At a stocking rate of 49,000 fish/ha, survival was 100% for silver carp × bighead carp, and 70% for the reciprocal. Zhongying et al. (1979) observed the following differences between bighead carp and silver carp hybrids and parental forms (15.0 to 25.0 mm body length):

	Hybrid	Parental forms
Gill rakers	80–108 1st arch	53–80 1st arch
Head length	31.9%–36% TL	32.3%–38.9% TL

Some hybrid crosses with *H. nobilis* have also been unsuccessful. Alikunhi et al. (1963), who attempted hybridization between several species of Indian and Chinese carps, reported that in the crosses – grass carp × bighead carp, silver carp × bighead carp, and rohu (*Labeo rohita*) × bighead carp – all the embryos died before hatching. A cross between catla (*Catla catla*) and bighead carp also failed; the hatchlings died on the first day.

2.4.2 Natural hybridization

Natural hybridization of bighead carp with silver carp was reported by Verigin et al. (1979) in the Syr-Dar'ya River, Soviet Union. Characteristics of the hybrids were intermediate between the parents, but most resembled those of the bighead carp.

3. BIONOMICS AND LIFE HISTORY

3.1 *Reproduction*

3.1.1 Sexuality

Bighead carp are typically heterosexual. External sexual dimorphism can be determined by examining the pectoral fins. In the male, these fins have a sharp edge along the dorsal surface of several front rays, whereas in the female this characteristic is absent (Anon. 1978). This secondary sexual characteristic of the male is formed long before maturity, and once formed, persists throughout its lifetime (Chang 1966).

3.1.2 Maturity

Sexual maturity of the bighead carp (Table 6) varies according to environmental and climatic conditions (Chang 1966; Huet 1970). The fish generally mature at a younger age in southern China than in the central and northern part of the country. Males usually reach sexual maturity one year earlier than females.

3.1.3 Mating

Like other carps and most other fishes, the bighead carp is promiscuous. The males actively chase the females, occasionally prodding their head against the belly of the females (Chang 1966). Much of the activity is generally at the surface of the water.

3.1.4 Fertilization

Fertilization is external and monospermic, occurring in the egg at the metaphase of the second maturation division (Youlan and Guojiang 1980). In the bighead carp, 1 mL of milt contained 48 million spermatozoa (Chang 1966). Fertilization of overripened eggs in a natural spawn is very low; overripeness causes irregular cell division and results in abnormal embryonic development.

3.1.5 Gonads and fecundity

Fecundity increases with increasing age and body weight. According to Vinogradov et al. (1966), for the bighead carp spawning for the first time in the Soviet Union, average production was 288,000 eggs. Chang (1966) reported that a bighead carp from the Yangtze River, China, having a body weight of 18.5 kg and gonad weight of 1.96 kg, produced 1,100,000 eggs. In southern China, the weight of the gonads of mature bighead carp may equal 17% to 20% of the total body weight. Sukhanova (1966) reported a working (stripped) fecundity of bighead carp as 478,000 to 549,000 eggs. After some females spawn, the ovaries become greatly reduced, and the residual eggs are only minute transparent oocytes (Chang 1966). In other females, however, a larger number of yolk-laden eggs remain; consequently, spawning may occur more than once per year. In Malaysian culture, the results of induced spawning experiments have shown bighead carp to become fully ripe in three separate 2-mo periods, thus having more than one spawning cycle per year (Chen et al. 1969).

3.1.6 Spawning

The spawning season of bighead carp in China extends from April to June, peaking in late May (Chang 1966). Natural reproduction occurs in channels of large rivers in swift current where velocities exceed 0.8 m/sec.

Table 6. *Maturity of male and female bighead carp in different localities (Alikunhi et al. 1963; Lin 1965; Sukhanova 1966; Kuronuma 1968; Vinogradov 1968; Nicolau and Steppoe 1970; Bardach et al. 1972; Chen 1976).*

Country	Sex	Age (years)	Size
China			
South	Male	2–3	–
	Female	3–4	5–10 kg
Central	Male	3–4	–
	Female	4–5	5–10 kg
Northeast	Male	5–6	–
	Female	6–7	5–15 kg
India	Female	3	67.2–70.3 cm 4.67–6.00 kg
Israel	Male	2	–
	Female	3	50 cm
Romania	Female	6	–
Soviet Union			
Krasnodar area	Male	4	–
	Female	5	–
Ukraine (Kiev region)	Male	7–8	–
	Female	8–9	–
(cooling	Male	3–4	–
reservoirs)	Female	4–5	–
Turkmen	Male	2–4	–
republic	Female	3–5	10 kg
Moscow	Male	9	–
	Female	10	–
Taiwan	Male	2–3	–
	Female	3–4	5+ kg

Native spawning grounds are primarily distributed in valleys of the Yangtze, Pearl, and Hwai rivers (Chang 1966), and spawning generally takes place at the confluence of two rivers or behind sandbars, stonebeds, or islands – areas characterized by rapid current and a mixing of water (Anon. 1970; Huet 1970). The monsoon rains cause numerous floods and a significant increase in the water level of these rivers during the spawning period. This is a necessary requirement for spawning because the floodlands provide nursery areas for the larvae and juveniles. Water temperature must be higher than 18 °C for spawning (Anon. 1970; Chunsheng et al. 1980). Spawning occurs in the Yangtze River when the temperature is 26 ° to 30 °C; generally from the middle to the end of May and in the West River when temperatures are 25 ° to 30 °C (Chang 1966) from late April to mid-August (Chen et al. 1969). One important spawning area in China includes a section of the Yangtze River, which extends about 100 km around E. Chong. Data on the environmental conditions of these spawning grounds were recorded during the spawning season (late April to late May) in 1953, 1954 and 1957 (Chang 1966). During 1953 and 1954, the spawning conditions included a temperature range of 18.3 ° to 23.5 °C, a rise in water level of 0.4 to 1.4 m and a range in water velocity from 0.78 to 2.26 m/sec. Water transparency was 6.16 cm. During 1957, most spawning was in late May, when the rise in water level ranged from 0.53 to 0.83 m. Dissolved oxygen was 7.43 to 10.13 mg/L, and pH was 7.8 to 8.0. Other conditions described include a long stretch of rock rapids upstream or at the junction of two branches of a river, a sand and gravel substrate, and turbidity associated with the rapidly flowing water.

Just before the spawning season, the bighead carp migrate upstream to the spawning grounds, which are characterized by rapidly flowing water. Spawning has been reported both at the surface of the water (Chang 1966) and underwater (Dah-Shu 1957), during any time of the day. During low-water, spawning occurs in the middle of the channel, but when the water is high,

accompanied by a rapid current, spawning is generally near shore (Chang 1966).

3.1.7 Description of Spawn

The spawn of bighead carp is non-adhesive and bathypelagic, maintaining a semi-floating state in a current and sinking to the bottom in stagnant water (Soin and Sukhanova 1972; Anon. 1970). This buoyancy is attained by the large amount of water the eggs absorb after deposition (Chang 1966), causing the volume of the perivitelline space to enlarge, reducing the specific gravity, and allowing the eggs to remain submerged in flowing water (Soin and Sukhanova 1972). As water is being taken up into the perivitelline cavity, the chorion stratifies; the outer layer is thinner and initially stretches more rapidly than the inner layer. When the water uptake is complete, the inner and outer layers of the chorion coalesce. The unswollen eggs are 1.4 to 1.5 mm in diameter and the diameter of the chorion in swelled eggs is 4.82 to 5.13 mm. Soin and Sukhanova suggested that the slight coloration of the pelagic eggs with carotenoid pigment, or the complete absence of this pigmentation, can be directly related to the excellent respiratory adaptations of the embryos.

3.2 *Pre-adult Phase*

3.2.1 Embryonic phase

The first change of the fertilized egg is the development of animal and vegetal poles. After a short time, the membrane separates from the yolk and a bulging germinal disc forms at the animal pole (Chang 1966). About 40 min after fertilization (22 ° to 26 °C), the cytoplasm forms into a blastodisc, and hydration of the perivitelline space is nearly complete (Anon. 1970). The diameter of the egg membrane at this stage is 4.70 to 5.22 mm (Soin and Sukhanova 1972). About 1 h after fertilization, the blastodisc undergoes division, forming blastomeres (Anon. 1970). The early (large-cell) morula begins after 2.5 h and the later (small-cell) morula develops after about 5 h, when hydration is complete. The diameter of the swollen egg membrane ranges from 4.82 to 5.63 mm. After 6 h, the cells migrate to form a multilayered outer wall, enclosing the blastula, an empty space in the center (Chang 1966; Sukhanova 1966; Anon. 1970).

Gastrulation begins at about 7 h (Anon. 1970). The blastoderm grows on the yolk sac surface toward the vegetal pole. A thickening node appears in one section of the blastomere fringe zone and the cells of the node rapidly divide, turning under and inward. This forms the rudimentary embryonic body, consisting of ectodermal, endodermal, and mesodermal germ layers, which thicken and lengthen according to the growth rate of the blastoderm. Gastrulation terminates at about 12 h. The rudimentary embryo appears as a thickened spindle, with the broad head section at the animal pole and the narrow tail section terminating at the vegetal pole. Chang (1966) regarded the gastrula stage as the most critical period during embryonic development because it is most sensitive to environmental changes.

The next stage involves the differentiation of the three embryonal germ layers into the rudiments of the principal organs (Sukhanova 1966; Anon. 1970). At 15 h, optic vesicles form, the notochord forms, mesodermal segmentation begins and cerebral vesicles differentiate. Between 16 and 21 h, crystalline lenses appear in the eyes, auditory vesicles are formed, the body is segmented into numerous myotomes, the notochord is distinctly visible, and the body begins to bend. At 22 to 29 h, the tail detaches from the yolk sac and the embryo begins to straighten. The length of the embryo is about 5 mm and the trunk has about 26 segments. Tail segementation is not yet complete. Numerous small vesicles that appear at the head and cardiac section represent hatching glands, that weaken the membrane for hatching. Movement of the embryo is more energetic, improving gas exchange and respiration and eventually assisting in hatching from the membrane.

Embryonic development is more rapid at higher temperatures. Hatching of the embryo from the membrane begins about 1 d after fertilization (22 °–26 °C) and may continue for several hours (Sukhanova 1966; Anon. 1970). Its duration depends upon water temperature and oxygen content; higher temperatures and low oxygen encourage more synchronous hatching.

3.2.2 Pro-larval phase

The pro-larval period lasts for about 3 d after hatching. Characteristics and development during this phase were described by Sukhanova (1966), Anon. (1970), and Soin and Sukhanova (1972). Upon hatching, the pro-larva is 5.5 to 6.0 mm long, and is motile under natural conditions; however, it is carried by the water current. Its trunk is relatively short compared to the tail. Myotomes number 24 to 26 in the trunk and 15 to 19 in the tail. Pigment is weakly developed in the anterior and ventral parts of the yolk sac and just below the eye. A pulsating heart with an auricle and ventricle is present and rudimentary otoliths are visible in the auditory capsules. Two days after hatching the embryonal vascular system forms and blood circulation begins. At 3 d, larvae are about 8.5 mm long. A movable gill-jaw apparatus forms and begins to function, branched gill vessels are present, and gill respiration begins; black pigment appears on the head, the rudiment of a swimbladder is observable, and movement is very active.

3.2.3 Mesolarval phase

Characteristics of this phase of bighead carp larval development were described by Dah-Shu (1957), Sukhanova (1966), Anon. (1970), and Soin and Sukhanova (1972). About 4.5 to 5 d after hatching, the

larvae are 8.5 to 9 mm long. The swimbladder is functional and respiration is exclusively by the gills. Mobility increases; the larvae swim in the water column and feed, but also continue to utilize yolk. Pigmentation on the head increases, and some melanophores appear on the dorsal part of the body and along the notochord. At 7 d, the yolk sac is completely resorbed and the larvae migrate along the shore, feeding exclusively on external food. The body is more extensively covered with melanophores than before. Lobes of unpaired fins (dorsal, caudal, and anal) are formed in the common fin fold. The first gill arch has 8 to 9 cylindrical rakers, and sharp pharyngeal teeth are embedded in the buccal epidermis. By 16 d, body length is about 10.5 to 12.5 mm. All unpaired fins are separated and fin rays have appeared. The end of the notochord is bent upwards with an indentation in the middle part of the caudal fin lobe. The swimbladder begins to form anterior and posterior sections. Ventral fins are developed. The lower jaw is elongated and projects further than the upper jaw.

At 20 to 28 d, paired fins are well developed and fin rays are formed. The ends of pectoral fins extend beyond the base of the ventral fins. The lobe of the dorsal fin ends at the level of the middle or posterior edge of the base of the anal fin. The lower jaw projects even further beyond the upper jaw. Both sections of the swim bladder are well developed. At a body length of 13.7 mm, bighead carp larvae have 23 to 25 gill rakers that are 110 to 160 μm long and 26 to 35 μm apart. During larval development pigmentation is weak, but it is visible, in the pre-anal fold area, in the region between the boundary of the dorsum and notochord, and between the notochord and intestine. One or two pigment cells are present at the base of the pectoral fins in a distinct semicircle.

3.2.3.1 Embryonic anomalies

Certain anomalies that appear during embryonic development result in death of the embryo (Anon. 1970). Dropsy may occur as a result of a disturbance of incubation conditions, such as extremely high or low temperatures or hypoxia. The water exchange of the embryos is disrupted, creating extreme hydration of the pericardial cavity. Embryonic deformities, such as curvature of the trunk or tail section, or disproportional development of different parts of the body, also may occur as a result of incubational disturbance.

3.2.3.2 Larval predators

Predation of larval fishes by predatory invertebrates is documented in culture situations (Anon. 1970). About 10 species of zooplankton are capable of depredating larval fish at early stages of development. *Cyclops* sp. is perhaps the most predaceous; however, aquatic insects (beetles, hemipterans and their nymphs, dragonfly larvae, etc.) also inflict damage. Predaceous diving beetles, *Hydaticus* sp., and tadpoles are also serious pests (Chen 1976).

3.2.4 Post larval stage (fry and fingerling)

Developmental characteristics of fry and fingerling stages were described by Dah-Shu (1957), Anon. (1970), and Soin and Sukhanova (1972).

When the larvae are about 1 mo old, small scales develop along the mid-line of the body. The anal fin contains 11 to 14 rays. The paired fins are well developed and extend beyond the base of the ventral fins. The dorsal fin extends to the middle of the base of the anal fin. An abdominal keel extends from the base of the ventral fins to the anus. By 1.5 mo, the entire body is covered with scales and openings of the lateral line are visible.

A number of protozoan parasites are known to infect bighead carp at these stages of development (Molnar 1971; Lucky 1984). *Cryptobia branchialis* is a flagellate that infects the gills. Sporozoa include *Eimeria sinensis* and *E. cheni*, which infect the intestine; *Myxobolus pavlovskii*, which infects the gills, and *Chloromyxum cyprini*. Ciliates include *Chilodonella cyprini*, *Ichthyophthirius multifilis*, *Trichodinella epizootica*, *Trichodina* sp., and *Apiosoma cylindriformis*, all of which infect the gills of bighead carp fry.

3.3 *Adult Phase*

3.3.1 Size/Longevity

In China, bighead carp generally reach 0.75 to 1.5 kg in their second year and 3 to 4 kg in their third year (Dah-Shu 1957).

In the Soviet Union, bighead carp commonly weigh 20 kg (Nikol'skii 1970). The maximum size reported for the bighead carp in the Ukraine is 40 kg at age 9 (Baltagi 1979). In the United States, the bighead carp sometimes reaches 18 to 23 kg in 4 or 5 yr (Henderson 1978).

3.3.2 Hardiness

The bighead carp must tolerate a wide range of environmental factors in its natural habitat, including extremes in water temperature from temperate to tropical and high turbidity during spawning (refer to section 2.3).

The bighead carp has been shown experimentally to be sensitive to several fish toxicants and chemicals. Henderson (1975) determined its tolerance to commonly used pond treatment chemicals at various dosage rates, including malachite green, copper sulfate, formalin, and potassium permanganate, within a 96-h period. In most experiments, total mortality was completed before 96 h of exposure. Malachite green caused 13% mortality at 0.3 part per million (ppm) and 100% mortality at 0.4 ppm and greater. For potassium

permanganate, mortality was 50% at 3.0 ppm and 100% at 4.0 ppm. Formalin caused 12% mortality at 80 ppm, yet no mortality occurred at 90 ppm during the 96-h period. Copper sulfate caused no mortality at 1.0 ppm, but total mortality at 2.0 ppm. Bighead carp were also very sensitive to rotenone. A concentration of 0.005 ppm caused 83% mortality in 24 h, and concentrations of 0.01 and 0.03 ppm resulted in total mortality in just 6 h.

Marking and Bills (1981) reported that mortality of bighead carp was 50% at a rotenone concentration of 0.0025 parts per billion (ppb) active ingredient after 96 h. Other 96-h LC50's averaged 0.600 ppb for antimycin, 468 ppb for Salicylanide I, and 0.355 ppm for GD-174 (2-[digeranylamino]-ethanol).

3.3.3 Competitors

Under certain situations bighead carp may be affected by both intraspecific and interspecific competition. In the southern Soviet Union, Vinogradov (1979) found that when yearling bighead carp were stocked at densities greater than 500 to 700/ha reduced growth resulted due to intraspecific competition for zooplankton. If zooplankton biomass is low, bighead carp switch to phytoplankton (Moskul 1977); consequently, competition may result from the combined stocking of silver carp with bighead carp in ponds. Buck et al. (1978a) found that bighead carp production in the United States was inversely correlated with the production of silver carp in pond polyculture, perhaps due to competition between the two. Chen (1934) reported that in China bighead carp attained better growth than silver carp in water that contained coarse particulate matter, yet did not match the growth of *H. molitrix* in water containing microscopic food material. Cremer and Smitherman (1980), who examined gill rakers of specimens 20–25 cm long, found that particles filtered by bighead carp in ponds were considerably larger than those filtered by silver carp. Bighead carp filtered zooplankton, phytoplankton, and detritus within the range of 17–3,000 μm; the majority of phytoplankton eaten was between 50 and 100 μm. Silver carp filtered both nanoplankton and net phytoplankton and detritus particles within the range of 8 to 100 μm; however, the majority of phytoplankton was between 17 and 50 μm.

Chen (1934) reported that bighead carp in China are outcompeted by grass carp when the two species are reared together in crowded situations and in equal num- bers. Opuszynski (1981) related a drop in production of common carp when stocked with bighead carp in Poland to food competition between the two species. The bighead carp also is reported to compete with common carp to some extent in the Soviet Union (Woynarovich 1968; Anon. 1970). According to Negonovskaya (1980), however, bighead carp in Soviet Union reservoirs generally eat food that does not put them in competition with native species. Henderson (1979) also found that bighead carp did not compete directly for food with many commercial species in the United States.

3.3.4 Predators

Negonovskaya (1980) reported that in reservoirs in the central Soviet Union, bighead carp are prey for pike–perch (*Lucioperca lucioperca*), northern pike (*Esox lucius*), Eurasian perch (*Perca fluviatilis*), and ide (*Leuciscus idus*). Predation on underyearlings is heavy and results in net economic loss.

3.3.5 Parasites, diseases, injuries, and abnormalities

Most parasite and disease outbreaks are in high density culture situations. Table 7 provides a list of disease-causing agents that reportedly infect bighead carp. Bauer et al. (1973) discussed these diseases and their control.

"White-skin disease" of bighead carp is caused by the bacterium *Pseudomonas dermoalba*, and is recognized by a whitening of the skin at the base of the dorsal and caudal fins. Mortality results if the fish are not treated. The most infectious fungal disease is caused by *Saprolegnia*, and is characterized by a cotton-like growth on the epidermis; it develops mainly as a result of the fish being stressed.

Bighead carp are also susceptible to numerous diseases caused by parasitic protozoans. Coccidial enteritis is caused by *Eimeria* sp. All developmental stages occur in any part of the gut, but intensive infection usually affects the foregut and midgut. The fish becomes sluggish and emaciated and the abdomen becomes soft and swollen. Yellowish strands of mucus, epithelial cells, and sporocysts project from the anus. This is a widespread disease in fish ponds in the Soviet Union and Hungary (Molnar 1976). Cryptobiasis is caused by *Cryptobia branchialis*, a flagellate that infects the gill filaments, causing them to become abnormallyred and eventually destroying them. *Ichthyophthirius multifilis*, which parasitizes the skin and gill epithelium, is characterized by the presence of small white tubercles on the body. Lesions of the cornea and blindness may also occur. This disease often causes mass mortalities in culture situations. Trichodiniasis is a disease caused by infusoria of the genera *Trichodina, Trichodinella*, and *Tripartiella*. These protozoans infect the skin and gills of bighead carp and inhibit circulation. Migala (1978) discovered several species of these genera, as well as other ciliates, infecting bighead carp reared in ponds in Poland. Another protozoan that parasitizes the gill epithelium of bighead carp is *Myxobolus pavlovskii.* In Czechoslovakia, Lucky (1978) found that the extensity and intensity of *Myxobolus* cysts increased with age; however, in Hungary, Molnar (1979) reported the infection to be most massive among bighead carp fry.

Table 7. *Disease-causing agents reported for bighead carp.*

Causative agent	Reference
BACTERIA	
Pseudomonas dermoalba	Bauer et al. 1973
P. fluorescens	Petrinec et al. 1985
FUNGI	
Saprolegnia sp.	Bauer et al. 1973
PROTOZOA	
Apiosoma sp.	Migala 1978
Chilodonella sp.	Musselius 1979
C. cyprini	Migala 1978
C. hexasticha	Migala 1978
C. cucullulus	Migala 1978
Crypotobia branchialis	Bauer et al. 1973
Dexiostoma campylum	
Eimeria sinensis	Bauer et al. 1973; Musselius 1979
E. cheni	Bauer et al. 1973
Frontonia acuminata	Migala 1978
F. leucas	Migala 1978
Glaucoma scintillans	Migala 1978
Icththyophthirius multifilis	Bauer et al. 1973; Anon. 1978; Musselius 1979; Migala 1978
Myxobolus pavlovskii	Lucky 1978; Molnar 1979
Sessilia sp.	
Trichodina sp.	Anon. 1978; Migala 1978
T. domerguei	Bauer et al. 1973; Migala 1978
T. pediculus	Bauer et al. 1973; Migala 1978
T. nigra	Bauer et al. 1973
T. reticulata	Bauer et al. 1973; Migala 1978
Trichodinella epizootica	Bauer et al. 1973; Migala 1978
Tripartiella bulbosa	Bauer et al. 1973; Musselius 1979
TREMATODA	
Dactylogyrus aristichthys	Bauer et al. 1973; Migala 1978
D. nobilis	Bauer et al. 1973
Diplostomum sp.	Musselius 1979; FAO 1979
D. spathaceum	Bauer et al. 1973
Posthodiplostomum sp.	Bardach et al. 1972
P. cuticola	Bauer et al. 1973
CESTODA	
Bothriocephalus gowkongensis	Bauer et al. 1973; Musselius 1979; Anon. 1978
Ligula intestinalis	Bauer et al. 1973
Diagramma interrupta	Musselius 1979
COPEPODA	
Synergasilus lieni	Bauer et al. 1973; Musselius 1979
Lernaea sp.	Bauer et al. 1973; Anon. 1978
Lernaea piscinae	Harding 1950; Shariff 1981

Trematodes reported to parasitize bighead carp include *Dactylogyrus* sp., which infects the gill filaments; *Diplostomum* sp., the metacercariae of which parasitize the eyes; and *Posthodiplostomum* sp., in which the larva infects the skin and subcutaneous tissue, depositing a black pigment around the cyst it forms in the skin. This infection is termed black-spot disease (Bauer et al. 1973; Musselius 1979).

The bighead carp also may be parasitized by cestodes, including *Ligula intestinalis* and *Diagrama interrupta*, which occur in the body cavity. Diagrammosis is reported in culture situations in the Soviet Union (Bauer et al. 1973). In China, the bighead carp is reported to be a carrier of *Bothriocephalis gowkongensis*, an intestinal parasite that causes mass mortalities of numerous pond cultured species (Bauer et al. 1973).

Several species of crustaceans parasitize fish in culture situations, causing disease outbreaks and mortalities. The bighead carp is parasitized by the copepod *Lernaea*, which attaches to the body surface, musculature, or gills, forming a deep ulcer, abscess, or fistula at the point of attachment. Harding (1950) first described this infection in bighead carp from Singapore, and Shariff (1981) reported its occurrence in the eyes and on the body surface of bighead carp in Malaysia. The copepod *Sinergasilus lieni* parasitized the gill filaments of bighead carp, compressing and rupturing the gill tissue and resulting in embolism and necrosis (Bauer et al. 1973).

One abnormality reported in bighead carp is "pugheadedness" (Shariff et al. 1986). This condition is characterized by a shortened upper jaw resulting in incomplete closure of the mouth and therefore decreased feeding efficiency. Its cause may be related to genetic factors, abnormal embryonic development, or environmentally induced larval abnormalities.

3.4 *Nutrition and Growth*

3.4.1 Feeding

The bighead carp is very efficient at using the food it ingests. Because of its gill raker size (section 1.3.2), it can filter plankton organisms from the upper and middle water layers it inhabits (Chen 1934; Verigin and Makeeva 1972; Cremer and Smitherman 1980). Aldridge et al. (personal communication), documented the presence of a translucent mucous coating on the gill rakers, allowing bighead carp to collect food particles as small as 20 μm in diameter. This mucous aggregation mechanism apparently serves a size selective function; large food particles (50 μm) such as zooplankton, large colonial algae, and large detrital particles, have sufficient bulk to pass over the top of the gill raker coat directly to the gullet. Smaller food particles become embedded in the mucus, and form aggregates that increase in size toward the distal end of the raker assembly, and then pass to the gullet. Pharyngeal teeth grind plankton to allow for the more efficient digestion of usable protein (Chen 1934; Nikol'skii 1954; Henderson 1976).

Feeding levels of 13-d-old larval bighead carp in the Soviet Union were highest at 1800 h and lowest at 0400 to 0600 h (Lazareva et al. 1977). In underyearling bighead carp (68 d old), feeding was highest at 1000 h and 1600 h and lowest at 1800 h and between 0400 and 0600 h. According to Sifa et al. (1980), the rhythm of feeding may be influenced by the intensity of illumination, dissolved oxygen, and water temperature. In China, bighead carp fed most intensely during July and August, for about 18 h each day; diurnal feeding peaked between 1200 and 2000 h. The daily ration (relation of total weight of food taken in one d to the weight of the fish) for bighead carp was 6.6%.

Moskul (1977) found that the feeding rate of 2-yr-old bighead carp in the Soviet Union increased toward evening, peaked at 2000 h, and was lowest at 0600 h.

3.4.2 Food

3.4.2.1 Larvae

The food particle size calculated as most suitable for larval bighead carp starting to feed is 150–200 μg (Dabrowski and Bartega 1984). Larvae 7–9 mm long eat primarily protozoa and zooplankton, including rotifers and nauplii, copepodites, *Bosmina*, and young *Moina* (Chang 1966; Bardach et al. 1972; Marciak and Bogdan 1979). At 10–17 mm, the larvae include Cladocera in their diet. At lengths between 18 and 23 mm, they begin to eat phytoplankton and at 24–30 mm they readily consume both zooplankton and phytoplankton (Ling 1967).

Korniyenko (1971) reported that larvae in Soviet Union culture fed on infusoria for 3–4 d after their transition to exogenous feeding, and then fed mainly on phytoplankton and zooplankton.

Lazareva et al. (1977) found that early larval stages of bighead carp in the Soviet Union ate phytoplankton (Protococcaceae), diatoms, blue-green algae, and infusoria. Between 0.009 and 0.015 g body weight, the larvae ate about 100% zooplankton (Rotatoria and Cyclopoida nauplii). Phytoplankton (diatoms) accounted for less than 0.1%. Between 0.010 and 0.047 g, zooplankton represented 69% of the food consumed and included copepodite stages of Cyclopoida, small Cladocera, and small chironomid larvae. Phytoplankton represented only 2% to 18% of the food and was composed mainly of diatoms. As the larvae increased in size, there was a gradual shifting of the food eaten from zooplankton to phytoplankton. Larvae between 0.014 and 0.125 g body weight ate only 39% zooplankton, mainly *Cyclops* and *Moina*. In ponds with low zooplankton biomass, blue-green and euglenoid algae accounted for most of the stomach contents.

In closed system culture of bighead carp larvae in Poland, Marciak and Bogdan (1979) found that artificial feed may be introduced when larvae are about 20 d old or 10 to 12 mm long. Dabrowski (1984) reported that bighead carp larvae (1.7 mg initial weight) grew better on a diet of live zooplankton (42.2 mg) than on an artificial compound diet (18.6 mg) after 15 d. Transfer to the artificial diet at a body weight of 5.6 mg showed good growth but high mortality was observed. The most successful artificial diet was a combination of yeast and freeze-dried pork liver.

3.4.2.2 Juveniles

Literature pertaining to food eaten by bighead carp suggests that the juveniles are very adaptable and wide-ranging in their feeding behavior.

Lazereva et al. (1977) reported that underyearling bighead carp in the Soviet Union ate less zooplankton than larval fish. When zooplankton biomass exceeded 1 g/m^3, it constituted 0.7% to 5.5% of the weight of the food bolus; when it exceeded 2 to 3 g/m^3, and the stocking rate of fish was low, it sometimes constituted 14% to 25% of the weight of the food bolus. The zooplankton eaten consisted primarily of *Cyclops*, *Moina* and *Chydorus*. As zooplankton biomass decreased to 0.5 g/m^3, however, the underyearlings fed on detritus and phytoplankton. Detritus constituted 87%–97% of the weight of food consumed, and phytoplankton usually did not exceed 0.1 to 1.0%. When zooplankton biomass was high (more than 20 mL/L), however, phytoplankton composed only 4% to 17% of the food eaten. Compared with phytoplankton content of the water, the percentage of blue-green algae in the food of underyearlings was considerably lower and that of diatoms was much higher. The authors interpreted these data to suggest a preference of bighead carp for diatoms and an avoidance of blue-green algae. Other authors suggested that when bighead carp are forced to eat blue-green algae, growth is slowed (Sukhoverkhov 1963; Verigin 1963).

In a study of the food of juvenile bighead carp in the United States, Cremer and Smitherman (1980) reported that the fish is wide-ranging in its foraging behavior, feeding actively on the pond bottom as well as in the upper and middle layers of the water column. Zooplankton was present in the intestinal contents during each sampling period. Intestinal detritus averaged 69.3% for bighead carp in fertilized ponds almost three times greater than for those caged in the ponds. The amount of phytoplankton present in intestines of bighead carp in ponds was only 6.5%, and consisted of predominantly Chlorophyceae; however, this percent increased to 66.8 for caged bighead carp. Food particles filtered were within the range of 17–3,000 μm; most phytoplankton was 50–100 μm. Cremer and Smitherman also observed bighead carp feeding on artificial pelleted feed.

3.4.2.3 Adults

According to Borutskiy (1973), the bighead carp is one of the most undemanding pond fishes of the Soviet Far East. It feeds primarily on zooplankton, but also eats phytoplankton and detritus (Table 8). Nikol'skii and Aliyev (1974) reported that bighead carp in the Karakum Canal, Soviet Union, fed predominantly on zooplankton (cladocerans, copepods, and to a lesser extent rotifers) during spring and early summer when the water level was high. During late summer and fall, they fed mainly on phytoplankton (blue-green algae, diatoms, and green algae). Aldridge et al. (personal communication) found evidence that food selectivity depends on plankton density and particle size. If plankton biomass was sufficient (5 mg/L) and a size differential existed within the plankton community, there was selectivity for the larger food items. When plankton biomass was sufficient, without a size differential, no food selectivity was observed.

Danchenko (1970) and Lazareva et al. (1977) observed that bighead carp in the Soviet Union switch to phytoplankton and detritus when zooplankton biomass is low. Food of bighead carp reared in foraging lagoons in the Soviet Union included a bulk of organic substances and mineral particles that were in suspension in the lagoon water, as well as zooplankton and phytoplankton (Moskul 1977). Aldridge et al. (personal communication) also noted a shift in the diet of bighead carp to detritus when plankton abundance was low.

3.4.3 Growth rate

Krzywosz et al. (1977) studied the growth of bighead carp in Lake Dgal Wielki, Poland. The fish were introduced into the lake after being held in ponds for nearly 4 yr. The average weight at stocking was 2,409 g. The increase in weight during the study is shown by age group in Table 9. Growth was calculated by using the Dahl-Lea method of back calculations (Table 10). Results indicated that the rate of growth was considerably higher in the lake than in the ponds, and remained high until the seventh year of life. The growth rate was higher than that of grass carp stocked in the lake. In both species, scale annuli were formed during late spring. The rate at which bighead carp increase in weight each year in selected lakes and reservoirs in the Soviet Union is shown in Table 11.

In culture systems, bighead carp show a high growth potential and outperform silver carp and grass carp in terms of net production (Woynarovich 1968; Newton 1980; Opuszynski 1981). In the south and middle zones of the Soviet Union, a considerable amount of zooplankton (not less than 3.5 mg/L) was required for bighead carp to reach peak growth potential (Vinogradov 1979). In the southern Soviet Union,

Table 8. *Food items reported for adult bighead carp.*

Item	Reference	Location
Zooplankton	Aldridge et al. (personal communication)	United States
	Burke et al. 1986	United States
	Rothbard 1981	Israel
	Baltadgi 1979	Soviet Union
	Leventer 1979	Israel
	Opuszynski 1979	Poland
	Vinogradov 1979	Soviet Union
	Henderson 1978	United States
	Ling 1977	China
	Moskul 1977	Soviet Union
	Grygierek 1973	Poland
	Roberts et al. 1973	China
	Anon. 1970	Soviet Union
	Danchenko 1970	Soviet Union
	Tang 1970	Taiwan
	Lin 1969	Taiwan
	Chang 1966	China
	Nikolsky 1963	Soviet Union
	Dah-Shu 1957	China
Cladocera	Opuszynski 1981	Poland
	Leventer 1979	Israel
	Csengeri et al. 1978	Hungary
	Lazareva et al. 1977	Soviet Union
	Moskul 1977	Soviet Union
Copepoda	Opuszynski 1981	Poland
	Leventer 1979	Israel
	Henderson 1976	United States
	Lin 1969	Taiwan
Rotifera	Csengeri et al. 1978	Hungary
Phytoplankton	Aldridge et al. (personal communication)	United States
	Baltadgi 1979	Soviet Union
	Opuszynski 1979, 1981	Poland
	Vinogradov 1979	Soviet Union
	Csengeri et al. 1978	Hungary
	Lazareva 1977	Soviet Union
	Moskul 1977	Soviet Union
	Nikol'skii and Aliyev 1974	Soviet Union
	Voropaev 1971	Soviet Union
	Anon. 1970	Soviet Union

Table 8. *Continued.*

Item	Reference	Location
	Danchenko 1970	Soviet Union
Diatoms	Csengeri et al. 1978	Hungary
	Nikol'skii and Aliyev 1974	Soviet Union
Algae	Verigin 1979	Soviet Union
	Vinogradov 1979	Soviet Union
blue-green	Aliev 1976	Soviet Union
	Henderson 1976	United States
	Janusko 1974	Poland
	Lin 1969	Taiwan
	Nikol'skii and Aliyev 1974	Soviet Union
	Voropaev 1968, 1971	Soviet Union
green	Janusko 1974	Poland
	Nikol'skii and Aliyev 1974	Soviet Union
	Lin 1969	Taiwan
Detritus	Aldridge et al. (personal communication)	United States
	Opuszynski 1981	Poland
	Baltadgi 1979	Soviet Union
	Vinogradov 1979	Soviet Union
	Lazareva et al. 1977	Soviet Union
	Danchenko 1970	Soviet Union
	Lin 1969	Taiwan
Organic substances/ minerals in suspension	Moskul 1977	Soviet Union
Insect larvae/aquatic insects	Henderson 1976	United States

Table 9. *Weight increase of bighead carp stocked in Lake Dgal Wielki, Poland (Krzywosz et al. 1977).*

Item	Age group						
	I[a]	II[a]	III[a]	IV	V	VI	VII
Average of body weight (g)	38	223	1,073	2,409	3,920	6,056	8,360
Range of body weight (g)	–	–	–	1,990–2,740	2,490–4,600	4,800–7,300	6,100–10,700
Variation coefficient (Vs%)	–	–	–	12,4	11,8	9,5	9,3
Average increment of body weight (g)	38	185	850	1,336	1,511	2,136	2,304

[a] Growth in ponds.

Table 10. *Back-calculated total lengths of bighead carp in Lake Dgal Wielki, Poland (Krzywosz et al. 1977).*

		Length of body (cm)						
Age group	n	1[a]	2[a]	3[a]	4	5	6	7
IV	19	11.6	24.4	37.9	47.5[b]			
V	54	12.7	24.2	39.0	49.5	55.4[b]		
VI	115	12.2	23.9	38.9	49.9	57.2	64.3[b]	
VII	59	13.1	25.1	40.6	51.7	59.4	66.7	71.6[b]
Average of body length (cm)		12.5	24.2	39.2	50.3	58.0	66.7	71.6
Average increment of body length (cm)		12.5	11.7	15.0	11.1	7.7	8.7	4.9
Range of body length (cm)		7.4–18.4	18.1–38.8	25.8–45.7	40.2–57.7	48.2–64.3	62.0–72.7	67.0–76.0
Variation coefficient (Vs%)		11.8	14.1	7.7	4.3	2.7	5.1	4.0

[a] Growth in ponds.
[b] Stands for average body length at the time of catching.

growth was reduced in yearling bighead carp stocked at densities greater than 500–700/ha. Vinogradov (1968) reported that 2-yr-old bighead carp reached weights of 400–600 g in the middle zones and 1,000–1,500 g in the southern zones. Baltadgi (1979) reported that bighead carp grew up to 2.5 kg/yr in ponds in the Ukraine, Soviet Union, and 5 to 6 kg/yr in power plant cooling reservoirs. Bighead carp 3 yr old may weigh 1.3–7.5 kg in the middle Soviet Union. After 5 yr, bighead carp reared in the Kuban estuaries of Soviet Union may reach 15–16 kg (Vinogradov 1968).

For bighead carp reared in tanks in England, the initial growth was 2.5 g/d, but decreased to 1 g/d after several months (Stott and Buckley 1978). After 5 mo, the final average weight was 156 g for fish averaging 21.1 cm in total length; a 25-fold increase over the weight at stocking.

Tal and Ziv (1978) found that in Israel, bighead carp fry stocked at 10,086 fish/ha gained an average of 1.68 g/d after 120 d. However, 1-g fish stocked at low densities of 570 fish/ha gained an average of 9.3 g/d after 126 d. In polyculture systems in Israel, bighead carp gained an average of 10–17 g/d when stocked at densities of 300–500/ha, and 3–10 g/d when stocked at 100–2,910 fish/ha. In one instance, bighead carp (1.5 kg) stocked at just 60 fish/ha had gained an average of 33 g/d after 75 d.

In aquaculture systems in the United States, Cremer and Smitherman (1980) compared the results for bighead carp (average weight at stocking 13.2 g) reared in ponds and cages with and without supplemental feed. The best growth (3.6 g/d) was obtained in fertilized ponds with supplemental feed; this was 57% greater than in ponds with fertilizer only. Growth was considerably less in cages than in ponds, but was 53% greater in cages with supplemental feed than in cages without the extra feed. Buck et al. (1978b) combined bighead carp with silver carp, common carp, grass carp, largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*) and hybrid buffalo (*Ictiobus cyprinellus* × *I. niger*) in a polyculture system. Bighead carp that averaged 45 g at stocking gained an average of 6.5 g/d for 173 d in ponds receiving a direct and constant supply of swine manure. Maddox et al. (1978) also studied the growth of bighead carp, silver carp, and tilapia raised on algae produced from swine manure in a United States polyculture system. They stocked 500 silver carp, 50 bighead carp, and 18 tilapia, averaging 2.3 and 7 g each, into 8,000-L experimental pools. Manure was applied directly to the ponds, or indirectly by feeding algae produced from the manure. The best results for bighead carp growth were obtained by directly applying manure to the ponds at a high rate

Table 11. *Rate of weight increase (kg) of bighead carp stocked in natural waters of the Soviet Union (Negonovskaya 1980).*

	Bighead carp age					
Water body	1+	2+	3+	4+	5+	6+
Lakes of the Pskov Region	0.34–0.46	1.1	–	–	–	–
Volograd Reservoir	0.37–0.51	– 1.0	0.9 2.6	–	2.5–	–
Lower reaches of Dnieper	– 1.9	1.5–	5.0	–	–	–
Veselovskoye Reservoir	–	1.2–1.5	3.5	3.0 3.5	5.9	–
Proletarskoye Reservoir	0.41	1.1–1.2	3.7	3.8–4.1	6.3–10.4	11.6–15.8
Shendzhiv Reservoir	1.8	3.2	–	–	–	–
Otkaznenskoye Reservoir	0.6	1.85	3.45	4.1	4.8	–
Cooling ponds of Mironov hydroelectric station	3.9	9.5	14.6	19.7	21.0	–

(90 L); the weight of bighead carp increased 115% over a 52-d period.

Henderson (1983) stocked bighead carp and silver carp in a sewage treatment lagoon in the United States. After 2 yr, bighead carp increased in biomass from 39.1 kg/ha at stocking to 1,510.4 kg/ha in one pond, and from 12.24 kg/ha to 589 kg/ha in another.

Green and Smitherman (1984) studied the growth of bighead carp fry and fingerlings raised for culture in the United States. The mean standing crop for fry stocked at 370,500 fish/ha was 296 kg/ha after 42 d, and the mean weight at harvest was 0.9 g in ponds and 0.7 g in tanks. The weight of fingerlings (0.9 g) stocked at 49,400 fish/ha and 98,800 fish/ha averaged 15.2 g and 11.3 g, respectively, after 60 d.

3.4.4 Metabolism

Moskul (1977) reported that the speed of food passage in the intestinal tract of 2-yr-old bighead carp in the Soviet Union ranged from 5.5 h to 7.33 h at 18 ° to 30 °C.

3.5 *Behavior*

3.5.1 Migrations and local movements

Migrations and movements of bighead carp are generally associated with reproduction and feeding (refer to sections 2.2, 3.1, and 3.4).

3.5.2 Schooling

Vinogradov (1979) described the bighead carp as a "quiet schooling fish, easily caught from lakes and reservoirs."

3.5.3 Responses to stimuli

Refer to sections 2.3 and 3.3.2.

4. POPULATION STRUCTURE

4.1 *Structure*

4.1.1 Sex ratio

No information was available on the sex ratio of bighead carp in the natural population. During natural spawning, however, it is generally 2–3 males for each female (Bardach et al. 1972; Anon. 1978). For artificial spawning, 1 to 2 males are used for each female.

4.1.2 Age composition

The age at which bighead carp reach sexual maturity varies according to environmental and climatic conditions (section 3.1.2). No information was available on longevity.

4.1.3 Size composition

The bighead carp is generally capable of reaching a size of 18–23 kg in 4 to 5 yr (Henderson 1978). The maximum size reported for the bighead carp in the Ukraine is 40 kg at age 9 (Baltagi 1979).

The annual rates of weight increase of bighead carp in natural waters of the Soviet Union and Poland are given in section 3.4.2.

4.2 *Abundance and Density*

4.2.1 Average abundance

Verigin et al. (1979) estimated the abundance of bighead carp eggs and prolarvae observed in a downstream drift in the Syr-Dar'ya River, Soviet Union, from 14 May to 5 June 1976 to be about 5% of the sample of about 600 eggs and larvae collected. Silver carp (85%) and grass carp (10%) composed the rest of the sample.

An estimation of the population size of bighead carp in the wild may be obtained from fishing statistics (section 5.5).

4.2.2 Changes in abundance

No specific information available.

4.2.3 Average density

No specific information on the average density of bighead populations available; refer to section 7.8 for annual production figures.

4.2.4 Changes in density

No specific information available. Changes in productivity of bighead carp in the basin of the Amu Dar'ya River increased from 8,200 kg/yr during 1967–69 to 5 million kg/yr in 1973 and 1974 (Aliev 1976; section 7.8).

4.3 *Natality and Recruitment*

4.3.1 Reproduction rates

According to Vinogradov et al. (1967), the average fecundity of bighead carp spawning for the first time in the Soviet Union was 288,000 eggs. Chang (1966) reported that bighead carp with a body weight of 18.5 kg and ovary weight of 1.96 kg produced 1,100,000 eggs in the Yangtze River, China. Bighead carp also have been shown to spawn more than once a year in culture situations (Chen et al. 1969).

4.3.2 Factors affecting reproduction

No information was found on the effect of density dependent factors on reproduction. Density independent factors, however, such as temperature, current velocity, and water depth associated with monsoons, do effect reproduction (refer to section 3.16).

4.3.3 Recruitment

Recruitment of bighead carp to the population depends on necessary environmental conditions for spawning and suitable nursery areas for the juveniles (refer to section 3.16).

4.4 *Mortality and Morbidity*

4.4.1 Mortality rates

No specific information on mortality rates of naturalized or indigenous populations was found. Available material deals with bighead carp reared in culture systems. Maddox et al. (1978), who studied the productivity of bighead carp, silver carp, and tilapia in a polyculture system in the United States, reported that bighead carp survival was 92% during the 52-d study. Newton et al. (1978), who combined five species at the rates (per hectare) of 250 bighead carp (1.39 kg), 1,250 silver carp (566 g), 50 grass carp (542 g), 50 largemouth bass, and 3,150 channel catfish (36 g), in a low intensity polyculture system in the United States, reported that bighead carp survival averaged 98% after 140 d.

Green and Smitherman (1984) reported survival of bighead carp fry stocked at 370,500 fry/ha to be 95% in ponds and 100% in tanks after 42 d. Survival of fingerling bighead carp was 91% and 71% for stocking rates of 49,000 and 98,800 fish/ha, respectively, after 60 d.

Tang (1970), who investigated the balance between fish species and available food in polyculture systems in Taiwan, stocked a 6.0-ha pond at the following rates (fish 3 to 9 cm long per hectare): 3,500 silver carp, 9,000 striped mullet (*Mugil cephalus*), 500 bighead carp, 200 grass carp, 10,000 common carp, and 300 sea perch (*Lateolabrax japonicus*). Total mortality of bighead carp was 16% after 11 mo. Mortality of bighead carp stocked with the same species in a series of reservoirs in Taiwan averaged 26%. Stocking rates (fish per hectare) were as follows: 400 silver carp, 200 grey mullet, 15 bighead carp, 80 grass carp, 10 black carp (*Mylopharyngodon piceus*), 200 common carp, and 50 sea perch.

Mortality of larval bighead carp under artificial rearing conditions can be estimated several hours before they hatch, by accounting for the percentage of unfertilized eggs as well as the percentage of poor-quality eggs that die during development (Anon. 1970). In the Soviet Union, fertilization of no less than 80%–85% of the eggs, combined with up to 5% deformities, can amount to a 10%–15% increase in mortality. With high quality spawn and normal incubation conditions, survival from eggs to larvae is no less than 70% to 80%. In China, only 60%–80% of the spawn is fertilized; therefore the survival rate of eggs to larvae is 40%–70% (FAO 1979).

4.4.2 Factors causing or affecting mortality

Certain abnormalities or deformities during embryonic development may result in death of the bighead carp embryo (Anon. 1970; section 3.2.3.1). Mortality of bighead carp larvae in culture ponds is caused largely by predation by zooplankton, insects or their larvae, and tadpoles (section 3.2.3.2).

Predation of underyearling bighead carp in lakes and reservoirs of the central Soviet Union is also documented (Negonovskaya 1980). Repeated introductions of bighead carp, silver carp, and grass carp into eutrophic lakes of the Pskov region that had a natural composition of fish fauna inevitably failed. In one month, all the young bighead carp and grass carp released were eaten by northern pike.

Mortality of bighead carp may also result from extreme changes in temperature or hypoxic conditions. Henderson (1978) reported that bighead carp reared in lagoons of a wastewater treatment plant in the United States suffered major mortalities from an unusually sudden drop in temperature, resulting in ice cover over 80% of the pond. A second fish kill occurred in the pond due to an oxygen depletion caused by the die-off of a heavy spring plankton bloom.

4.4.3 Factors affecting morbidity

Morbidity may be caused by parasites and diseases (section 2.4 and 3.3.5), adverse water quality or hydrological conditions (section 2.3), or starvation. Results from experiments in lakes of the Pskov region, Soviet Union, indicated that at a temperature of 12 °C, feeding activity of bighead carp fingerlings decreased to 50% of the level of active feeding (20 °–22 °C); feeding was minimal at 10 °C, and at 5 °C the fish ceased to react to outer stimuli (Negonovskaya 1980).

Henderson (1975) and Marking and Bills (1981) documented the extreme sensitivity of bighead carp to rotenone and other fish toxicants and chemicals (section 3.3.2).

4.4.4 Relation of morbidity to mortality rates

The introduction of underyearling bighead carp into waters in the central and northern latitudes of the Soviet Union with saturated fish fauna has usually failed, largely due to predation. According to Negonovskaya (1980), there is a considerable decrease in activity of bighead carp and other phytophagous fishes as water temperature cools; therefore, in waters with early fall cooling and heavy predation, these fish become very accessible prey for predatory fish such as the pike-perch, northern pike, Eurasian perch, and ide.

4.5 *Dynamics of Population*

No specific information was found on the demography of acclimatized bighead carp populations as a whole. Results from catch statistics in the Soviet Union, however, indicated that bighead carp are becoming more abundant in the overall fishery of several lakes and reservoirs (section 5.5).

4.6 *The Population in the Community and the Ecosystem*

In its native range, the bighead carp is associated with other phytophagous species such as the silver carp, grass carp, common carp, mud carp (*Cirrhina molitorella*), and black carp. Selected combinations of these fishes have been used internationally in natural waters and aquaculture facilities to increase total fish production and improve water quality.

Due to their diverse food habits, the bighead carp, silver carp, and grass carp have been used extensively in the management of inland waters of the Soviet Union (Aliev 1976; Vinogradov 1979). In the Khauz Khan reservoir, the bighead carp and silver carp have been responsible for preventing intensive blooms of phytoplankton, particularly blue-green algae, and in combination with grass carp have had an appreciable effect in increasing the biomass of zoobenthos, particularly Chironomidae (Nikol'skii and Aliyev 1974; Aliev 1976). These fish also were responsible for increasing the total fish productivity of this reservoir to 54.6 kg/ha in 1973. Similar increases in productivity due to the introduction of these fishes was reported in Turkmenistan, Soviet Union (Aliev 1976). Galinskiy et al. (1973) suggested using bighead carp to provide more effective use of available food resources in the Dneprodzerzhinsk Reservoir, Soviet Union.

In pond culture in the Soviet Union, production increases from 170 kg/ha in 1965 to 490 kg/ha in 1969 and 700 kg/ha in 1973 were directly related to the introduction of the combined species of phytophagous fish bighead carp, silver carp, and grass carp (Nikol'skii and Aliyev 1974).

There are reports in pond situations of competition for food between bighead carp and common carp (Woynarovich 1968; Anon. 1970; Opuszynski 1981), and bighead carp and silver carp when zooplankton biomass is reduced (Moskul 1977; Buck et al. 1978a). Negonovskaya (1980), however, reported that in reservoirs in the Soviet Union, bighead carp generally utilize food that does not result in competition with native species.

Water quality improvement by bighead carp and silver carp also has been documented under experimental conditions. Henderson (1978, 1983), who reared bighead carp and silver carp in wastewater treatment lagoons in the United States to evaluate their effect on water quality, reported that the addition of these fish stimulated 'controlled' phytoplankton growth, increased oxygen demand due to photosynthesis, and decreased biological oxygen demand (BOD) by preventing plankton die-offs and decay. The increase in algae production caused by these fish created a subsequent increase in pH, which in turn is believed to have caused a reduction of coliform bacteria in the system.

Germany is also using the bighead carp in combination with grass carp and silver carp for biological control of undesirable aquatic vegetation in management ponds (Bohl 1971).

5. EXPLOITATION

5.1 *Fishing Equipment*

In China, before the advent of induced spawning (section 7), traps were placed along river embankments to collect drifting bighead carp fry (Lin 1949). The most popular devices used were long, conical, fine-mesh bag nets fastened to bamboo or China fir poles (Lin 1949; Dah-Shu 1957; Bardach et al. 1972). Adult bighead carp, generally brood stock, were captured by trolling with bait, or in gill nets, or in triangular nets hung from fishing vessels (Chang 1966). There are also reports of fishermen using tamed otters and cormorants to capture fish.

5.2 *Fishing Areas*

5.2.1 General geographic distribution

In China, bighead carp fry and fingerlings are collected downstream from their major spawning grounds, including the middle and lower reaches of the Yangtze River (Dah-Shu 1957; Chang 1966), as well as the West, Hwai, and Chientang rivers (Chang 1966). Adult bighead carp are distributed in rivers in the North China Plain and South China (section 2.1.1). Welcomme (1981) reported that the bighead carp is caught by angling in the basin of the Danube River in Europe.

5.2.2 Geographic range

In the Soviet Union the bighead carp has been successfully acclimatized in waters located at a latitude of 45 °N and further south. North of this latitude the commercial catch is small or non-existent (Negonovakaya 1980).

5.2.3 Depth ranges

Bighead carp fry and fingerlings are captured in conical nets at the surface of the water. Adults are generally taken with nets at a depth of about 2 m or by trolling with bait at slightly lower depths (Dah-Shu 1957; Chang 1966).

5.3 *Fishing Seasons*

In China, bighead carp fry, fingerlings and adults are generally collected during the reproductive season, from May to June (Chang 1966).

5.4 *Fishing Operations and Results*

5.4.1 Effort and intensity

No available information.

5.4.2 Selectivity

No available information.

5.4.3 Catches

According to Negonovskaya (1980), results from catches of bighead carp stocked as yearlings in lakes and reservoirs of the Soviet Union proved more favorable than results from those stocked as under-yearlings, due to a decrease in predation. In Kakhov Reservoir, catches of bighead carp that fluctuated between 1,800 and 5,700 kg/yr in 1971–1975 increased to 32,000 kg in 1976, to 91,800 kg in 1977, and to 320,000 kg in 1978. In Tsimlyansk Reservoir, catches increased from 2,400 kg in 1975 to 11,500 kg in 1976 and 26,000 kg in 1977. Of these catches, 90%–95% constituted year-classes corresponding in age to fish stocked as yearlings. Yearling bighead carp (average weight 14 g) stocked at 70 fish/ha in a lake in the Pskov region, Soviet Union, where local ichthyofauna was depleted, resulted in a commercial return of 78%. In inland waters of Turkmenistan, Soviet Union, catches of bighead carp decreased from 11,400 kg in 1967 to 6,400 kg in 1969. Yet, with the removal of a fishing ban in 1970, catches increased to 47,000 kg and continued increasing to slightly more than 5 million kg in 1973, and then to slightly less than 5 million kg in 1974 (Aliev 1976; Table 9). Catches of bighead carp and silver carp in the Khauz Khan reservoir of the Karakum canal, Soviet Union, increased from about 5,000 kg in 1969 to 484,100 kg in 1973 (Nikol'skii and Aliev 1974; Aliyev 1976; Table 12).

6. PROTECTION AND MANAGEMENT

6.1 *Regulatory Measures*

6.1.1 Limitation or reduction of total catch

No available information.

6.1.2 Protection of portions of the population

In China, conservation laws pertaining to the fisheries resources have been applied many times throughout history. Regulations generally include setting size limits and restricting or prohibiting fishing activity for spawning fish during the breeding season and on the spawning grounds (Chang 1966). Before 1970, a ban was imposed on fishing for phytophagous fishes in waters of the Turkmenistan Republic, Soviet Union (Aliev 1976).

6.2 *Control or Alteration of Physical Features of the Environment*

6.2.1 Regulation of flow

No available information.

6.2.2 Control of water levels

No available information.

6.2.3 Control of erosion and silting

Ponds are drained to remove accumulated organic matter on the bottom and pond beds are leveled to prevent erosion (Bauer et al. 1973; refer to section 7.5.1).

6.2.4 Fishways at artificial and natural obstructions

No available information.

6.2.5. Fish screens

Screens or traps may be installed at pond outlets to prevent the escape of fish while draining the pond or to aid in sorting the fish according to size (section 7.9.1).

Table 12. *Catches of bighead carp in waters of the Soviet Union (Aliev 1976).*

	Turkmenistan		Khauz Khan Reservoir	
Year	Weight (kg)	Total produced (%)	Weight (kg)	Total produced (%)
1967	11,400	2.3	–	–
1968	6,700	1.4	800	0.7
1969	6,400	1.5	5,000	4.6
1970	47,000	7.2	41,300	23.9
1971	197,000	2.3	164,500	61.5
1972	357,100	38.4	335,900	74.6
1973	518,000	42.8	484,100	73.9

6.2.6 Improvement of spawning grounds

No available information.

6.2.7 Habitat improvement

No available information.

6.3 *Control or Alteration of Chemical Features of the Environment*

6.3.1 Water pollution control

When bighead carp are reared in ponds, proper management involves monitoring water quality to prevent potential mortality and using the appropriate dosage of chemicals for pond treatment (sections 2.3 and 3.3.2).

6.3.2 Salinity control

It is important to insure that salinity concentrations do not approach the lethal limits for bighead carp.

6.3.3 Artificial fertilization of waters

Materials used for pond fertilization are described in section 7.5.

6.4 *Control or Alteration of the Biological Features of the Environment*

6.4.1 Control of aquatic vegetation

The bighead carp, silver carp, and grass carp are used in combination in lakes and reservoirs of the Soviet Union to improve water quality by controlling aquatic macrophytes (grass carp) and phytoplankton blooms (bighead carp and silver carp). Nikol'skii and Aliyev (1974) reported that in some reservoirs of the Karakum Canal, into which only grass carp have been introduced, the control of aquatic macrophytes caused intensive development of phytoplankton – particularly blooms of blue-green algae. Upon introduction of bighead carp and silver carp, however, the development of phytoplankton was greatly limited, and undesirable algae blooms were eliminated.

6.4.2 Introduction of fish foods

No available information.

6.4.3 Control of parasites and diseases

Refer to section 7.7.

6.4.4 Control of predation and competition

Predation on bighead carp in small lakes and reservoirs can be controlled by suppressing or eliminating potential predator species. In large bodies of water, however, it is recommended that bighead carp be stocked at a size sufficient to reduce predation pressure (Negonovskaya 1980).

In culture, predators of fry and fingerling bighead carp are eliminated during pond preparation by applying quicklime and tea-seed cake, or by using certain chemicals (section 7.5.1).

In the southern Soviet Union, intraspecific competition of bighead carp may be alleviated by stocking at densities less than 500–700 yearlings/ha (Vinogradov 1979). Potential interspecific competition between bighead carp and silver carp may be reduced by lowering the stocking density of silver carp to 300–455 kg/ha, or by rearing fewer silver carp between June and September, when the bighead carp grows most rapidly (Anon. 1978).

6.4.5 Population manipulation

In production ponds, fish populations are continually manipulated by harvesting or culling to achieve the optimum stocking density that encourages individual growth and reduces stress (section 7).

6.5 *Artificial Stocking*

6.5.1 Maintenance stocking

The introduction of yearling bighead carp into waters of the central Soviet Union was necessary to maintain stable populations, since earlier introductions of underyearlings inevitably failed due to excessive predation (Negonovkaya 1980). In lakes and reservoirs in China, where management is less intensive, the bighead carp is one of the major species stocked (Anon. 1977; Tapiador et al. 1977), and a density of 4,860 fish/ha is generally used (FAO 1979). Maintenance stocking for aquaculture operations is discussed in section 7.4.

6.5.2 Transplantation; introduction

Refer to section 2.1.2.

7. POND FISH CULTURE

7.1 *Procurement of Stocks*

Bighead carp are obtained for culture either from the wild as fry, fingerlings, or adults, or through induced breeding by hypophysation (section 7.3).

7.2 *Genetic Selection of Stocks*

During artificial spawning, milt from two to four males is used to fertilize eggs from one female, thereby genetically improving the stocks (Dah-Shu 1957; Chen et al. 1969; Anon. 1970).

7.3 *Spawning (artificial; induced; natural)*

Due to the strict reproductive requirements of the bighead carp, initial attempts at production concentrated on obtaining brood stock and fry from the wild. The advent of artificial reproduction by hypophysation made large-scale culture of this species possible, and eliminated the dependence on wild stocks.

Inducing the spawning of bighead carp by using pituitary hormones was first attempted in mainland

China in 1954, and was experimental until 1961 (Kuronuma 1968). It was done in Taiwan and in the Soviet Union in 1963 (Tang 1965; Halver 1972). Techniques include first obtaining sexually mature, fully ripe brood stock; males should be flowing with milt, and females should have full, flaccid abdomens. Spawning is generally induced by injecting fresh or acetone-dried cyprinid pituitary glands that have been suspended in a saline solution. The pituitary of sexually ripe common carp is used most often; however, the nonspecificity of the hypophysial hormones permits the use of glands from other cyprinid species (Bardach et al. 1972; FAO 1979). Gonadotropins, including Puberogen, Gonagen, Synahorin, and human chorionic gonadotropin (HCG) are also used to induce ovulation, and may be combined with carp pituitary (Tang 1965). The generally accepted dosage for bighead carp is 2 to 3 mg dried cyprinid pituitary, three fresh pituitary glands from fish of equivalent size, or 700 to 1,000 IU HCG per kilogram of spawner (Bardach et al. 1972). The synthetic luteinizing hormone-releasing hormone (LH-RH) analogue, des-GLY10 [D-Ala6] LHRH ethylamide, is also effective (Rottmann and Shireman 1985).

Females usually receive two injections, the first of which contains from 1/8 to 1/10 of the total dosage (Anon. 1970; Vinogradov 1968, 1979; Bardach et al. 1972; Rothbard 1981). The second injection is generally given 6–24 h after the first. This dosage can be determined more precisely from an estimation of the gonadal status of the female on the basis of her maximum girth. The dosage given is directly related to body girth (Anon. 1970; Rothbard 1981). Variation among dosages and intervals between injections are shown in Table 13.

Hypophysial injections are often given to males to ensure that sufficient milt will be obtained. Only one injection is given, generally at the time of the female's second injection (Lin 1965; Vinogradov 1968; Anon. 1970; Tapiador et al. 1977; Rothbard 1981). Rottmann and Shireman (1985) found the LH-RH analogue to be especially useful for stimulating male bighead carp to produce milt. One injection of 10 μg/kg body weight was effective.

Injections are both intraperitoneal, generally given at the base of the pelvic or pectoral fins (Kuronuma 1968), and intramuscular, administered at the base of the dorsal fin (Dah-Shu 1957; Rothbard 1981; Rottmann and Shireman 1985). After the fish are injected, they are placed in a pond and either allowed to spawn naturally or removed for artificial spawning.

For natural spawning, a sex ratio of two to three males for each female is used (Bardach et al. 1972; Anon. 1978). Optimum conditions for the brood stock include

Table 13. *Procedures for artificial injection of female bighead carp.*

Locality	Injection (type & dosage) 1st:2nd:3rd	Interval between injections (h)	Reference
China	100–150:900–1350 IU/kg HCG	–	Anon. 1978
India	2:5:5 mg/kg rohu pituitary	6, 10.5	Alikunhi et al. 1963
Israel	0.3–2.7 mg/kg dried pituitary	24	Rothbard 1981
Malaysia	5–7.5:5–7.5 mg/kg carp pituitary	5	Chen et al. 1969
Soviet Union	0.5–1:3–6 mg/kg dried pituitary	–	Anon. 1970
Taiwan	1.0–1.5 mg/kg carp pituitary + 4–10 rabbit units 4–10 Synahorin: 1.0–1.5 mg/kg carp pituitary + rabbit units Synahorin	6	Lin 1965; Tang 1965
United States (Arkansas)	100 IU HCG + 1 mg/kg whole carp pituitary: 500 IU HCG + 3 mg/kg whole carp pituitary	6	Henderson 1979

water temperatures from 22° to 29 °C, a current velocity of 0.2 to 0.4 m/sec, and a dissolved oxygen content of at least 4 ppm (Kuronuma 1968; Bardach et al. 1972; Vinogradov 1979). The gonads of the fish ripen 6–20 h after injection. The rate of ripening is temperature dependent (Bardach et al. 1972; Vinogradov 1979):

7–10 h at 26°–28 °C
9–11 h at 23°–25 °C
10–12 h at 20°–22 °C

Spawning readiness is first indicated by chasing, and the fish spawn about 30–90 min later (Kuronuma 1968; Bardach et al. 1972).

For artificial spawning, the proper sex ratio is one to two males for each female (Anon. 1978). After 15–30 min of spawning, the brood fish are removed from the pond before courtship becomes too vigorous (Lin 1965). If the brood fish are maintained in tanks, the female usually occupies a shaded corner. When ripening, however, she begins to swim around the tank walls near the surface (Rothbard 1981). Periodic inspection of the female also helps determine when ripening occurs; ovulation is detected by a swollen distended abdomen (Lin 1965; Anon. 1978; Starling 1981). When peak ripeness is reached, spawn from the brood fish is obtained by hand stripping – gently pressing the belly and abdomen to release eggs and milt.

The most commonly used technique for artificial fertilization is termed the "dry method" or "Russian method" (Lin 1965; Chang 1966; Kuronuma 1968; Chen et al. 1969; Vinogradov 1968, 1979; Anon. 1970, 1978; Rothbard 1981). This involves collecting the eggs into a dry pan and adding a small volume of milt (2 to 3 cc milt is required to fertilize 1 L of eggs). The mixture is carefully stirred with a bird feather or gently swirled for 1 to 2 min to ensure complete mixing. Fresh water is then added to activate the sperm to fertilize the eggs. Prinsloo and Schoonbee (1983) recommended adding 2–4 g/L urea to the eggs and milt after stripping to increase sperm activity, and stirring the mixture for 30–60 sec. The eggs should be rinsed 3–4 times. They also recommended rinsing the eggs in a 0.5 g/L solution of tannic acid for 10–20 sec to toughen the membrane and reduce susceptibility to *Saprolegnia*.

After fertilization the eggs are transferred to hatching devices. A variety of devices are used, but all are designed to allow water to enter the container from beneath and pass among the eggs rather than over the top. This ensures a steady circulation of water around each egg and increases the rate of gas exchange (Bardach et al. 1972). Optimal conditions for hatching include a steady flow rate of 0.2 to 3 m/sec, temperature between 24° and 30 °C, pH of 7.4 to 8.5, and a dissolved oxygen concentration greater than 4 mg/L (Tapiador et al. 1977; Chang 1966).

7.4 *Holding of Stock*

7.4.1 Fry

After the yolk sac is absorbed, the fry of bighead carp are transferred to nursery rearing ponds that may vary from 100 m^2 to 2 ha, and should be at least 0.5 to 1 m deep (Bardach et al. 1972). Water temperature should be maintained just above 20 °C and dissolved oxygen kept between 6 and 12 mg/L (Vinogradov 1979). Treatment of ponds before stocking is discussed in section 7.5.

Stocking rates vary according to pond productivity. Anon. (1970) suggested that up to 3 to 4 million larvae/ha can be stocked in prepared ponds, and up to 6 to 7 million/ha in highly productive ponds fertilized with organic matter. Chen (1976) recommended stocking 3 million fry/ha for growth, or 5 million/ha if the fish are to be purposely stunted. In general, bighead carp fry are maintained in nursery ponds for 3–4 weeks until they reach fingerling size, about 3 cm long (Anon. 1978; Tapiador et al. 1977; FAO 1979; Bardach et al. 1972).

7.4.2 Fingerlings

Bighead carp fingerlings may be raised in either monoculture or polyculture systems. In Chinese monoculture, fish 3–6 cm long are stocked at the rate of 280,000/ha and fish 6–12 cm long at 60,000–100,000/ha (FAO 1979).

Stocking rates vary in polyculture systems because the growth rates of the fingerlings differ. In China, combined fingerling species are initially stocked at a rate of 4,500,000/ha and raised for about 30 d, until they reach a length of 6 cm. They are then transferred to another pond at different stocking rates, and raised to 12 cm in length. The lower stocking rates generally produce the larger fingerlings (FAO 1979; Tapiador et al. 1977).

7.4.3 Adults

In the Kwangtung Province of China, bighead carp are maintained at weights of 380 to 530 kg/ha from May to September (Anon. 1978). For fish stocked at 380 kg/ha, individual growth can be increased by 0.4 to 0.6 kg/mo; in those stocked at densities greater than 530 kg/ha, growth is restrained by 0.05 to 0.3 kg. Brood fish are reared in polyculture, although the species combinations vary according to the major species desired. The total stocking density of several species in Kwangtung Province is 1,500 to 2,250 kg/ha (Tapiador et al. 1977). When the bighead carp is the main species raised, stocking combinations are as follows:

Bighead carp (7–12 kg) stocked at 80 to 96/ha
Grass carp (5 kg) stocked at 90 to 128/ha
Silver carp (2 kg) stocked at 32 to 48/ha
Monosex common carp (0.25 kg) stocked at 320 to 480/ha

In the Soviet Union, bighead carp brood fish are held at low densities (50 fish/ha) during summer and maintained to achieve an average growth of no less than 1 kg during this time (Anon. 1970).

7.5 *Pond Management*

7.5.1 Pond preparation

Before fry and fingerling ponds are stocked, they are treated to control infections and cleared to eliminate potential predators. Commonly used pond preparation toxicants are tea-seed cake and quicklime (Lin 1949; Chen 1976; FAO 1979). Tea-seed cake is applied at the rate of 525–675 kg/ha, and quicklime at 900 to 1,050 kg/ha in dry ponds, and 1,975 to 2,250 kg/ha in wet ponds having a water depth of 1 m (Tapiador et al. 1977). Within a week to a month, the pond is leveled, filled, and fertilized (Lin 1949; Bardach et al. 1972; Chen 1976). If predatory insects or larvae become reestablished, toxicants are used to kill them (Anon. 1978).

Pond estivation is also an important management practice for ponds in which organic matter has accumulated on the bottom for a long time (Bauer et al. 1973). Every 4 to 5 yr, ponds should be drained from one fall to the next. During spring, pond beds should be leveled, collecting ditches cleaned, residual water drained, and silt removed. This process restores the natural productivity of the pond and helps to eliminate certain disease-causing agents, as well as their intermediate hosts.

7.5.2 Pond fertilization

The use of organic or inorganic fertilizers helps to achieve a high rate of food reserve production by supplying essential nutrients to stimulate the growth of plankton (Vinogradov 1979). Organic fertilizers include human and animal manures, decaying odoriferous plants such as goatweed (*Agertium conyzoides*), and agricultural by-products such as rice, bran, soybean cake, oil-seed cake, grain husks, and sewage (Chang 1966; Ling 1967; Prowse 1967; Bardach et al. 1972; Brown 1977).

Nursery ponds in China are fertilized with an initial application of goatweed, with or without cow dung, at a rate of 1,200 to 2,000 kg/ha. As a substitute, a 7:1 mixture of cow dung with ammonium nitrate or ammonium sulfate may be applied at 800 kg/ha. Within a week after fertilization, the water should turn greenish-brown, indicating an abundance of phytoplankton. Fry are stocked after undecayed pieces of fertilizer are removed. After stocking, fertilization for bighead carp fry is continued with goatweed at the rate of 100 kg/ha every 3 d (Bardach et al. 1972).

The rate of application of organic manure in ponds in southern China varies from 5,625 to 10,125 kg/ha, applied in three portions, the first dose being larger than the other two (Tapiador et al. 1977). In Singapore, China, fish ponds are arranged to receive excess fertilizer, compost, and soil minerals from other agricultural sources such as terrestrial crops and livestock. Pig manure is periodically washed into the ponds and generally provides the only source of direct fertilization. The pond eventually becomes a dilute solution of fertilizer, which in turn is used for land crops, and the bottom sludge is periodically removed for use in vegetable beds. In this way, fish production plays an integral role in other agricultural operations (Bardach et al. 1972). Pigs also are used as sources of fertilizer for Chinese carp ponds in other areas of China, Hong Kong, Thailand, and in the United States (Prowse 1967; Bardach et al. 1972; Buck et al. 1978a,b). The pigs are maintained in pens above the pond so that waste drops directly into the water.

Organic manures traditionally have been used for fertilizing ponds in the Far East; however, there is evidence that inorganic fertilizers (N-P-K) are superior. In Malaysia, it has been shown that once a pond has been treated with lime to establish a neutral pH, superphosphate (P_2O_5) is the only fertilizer needed to enhance fish production (Bardach et al. 1972). When compared to organic fertilizers, superphosphate applied at a rate 333 kg/ha, produced better growth of blue-green algae and reduced production of superfluous algae, lessened the danger of dissolved oxygen deficiency, and diminished the need for supplementary feeding. Superphosphate also has proven effective for increasing productivity of fresh-water ponds in Taiwan (Lin and Chen 1967). Research indicated that a dosage of 40 kg/ha of P_2O_5 is the most efficient and economical. At this dosage, 1 kg of P_2O_5 can produce 10 kg of marketable fish. It has been shown that fish yield is not necessarily proportional to the dosage of P_2O_5. The principal affect of this fertilizer is on the growth of fish that feed on phytoplankton and zooplankton; the net weight of bighead carp increased 167% when P_2O_5 was used. In polyculture systems where the bighead carp is a principal fish, Lin and Chen (1967) suggested the following criteria for testing phosphate fertilizers:

Pre-fertilization annual production (kg/ha)	P_2O_5 needed (kg/ha)
< 200	80
400	60
600	40
> 800	20

7.6 *Food and Feeding*

Supplementary feeding of bighead carp, either in monoculture or polyculture systems is secondary to

fertilization, yet it is practiced to obtain rapid growth of the fish and achieve a greater stocking density. In general, artificial feeds encompass a wide variety of materials of both plant and animal origin that can be easily and inexpensively obtained.

Supplementary feeds are generally given to bighead carp fry 3 to 10 d after they are stocked into the nursery ponds. These feeds include soybean milk, applied at the rate of 300 or 500 g beans/50,000 fry per day, egg yolk, milk powder, and liver extract (Bardach et al. 1972; Chen 1976). After several days, these feeds should be replaced with soybean and peanut meal, wheat flour or bran, or rice bran (Tapiador et al. 1977; FAO 1979) in quantities of 4% to 10% of the total weight of fry (Chen 1976).

Fingerlings should be fed similarly to fry (rice bran, soybean cake, and peanut cake), but at increased rates (FAO 1979). In China, bighead carp fingerlings may be combined with other species of Chinese carps, and reared together in a polyculture system. Supplemental feeds are given at the rate of 150 to 300 kg/ha of duckweed and 3,000 to 4,500 kg/ha of green manure every 10 d (Tapiador et al. 1977). Peanut cake at 30 kg/ha and vegetable tops at 45 kg/ha are provided as daily supplements. Generally, in Chinese polyculture systems, supplementary feeds given to fish consist of 99.6% rough plant material (grass and vegetable tops), and only 0.4% fine food (residues of fermented products such as soybean curd, soybean, and peanut cake and rice and wheat bran).

In polyculture systems in Taiwan, where bighead carp are often combined with other Chinese carps, common carp, mullet, and milkfish (*Chanos chanos*), the principal feed materials include grass, aquatic plants, duckweed, banana leaves, vegetable waste, bean leaves, rice bran, peanut cake, soybean cake, wheat bran, trash fish, offals, blood meal, fish meal, earthworms, and silkworm pupae (Chen 1935; Ling 1967). The amount of green fodder given per day is about 15% to 20% of the estimated total weight of the fish fed. In heavily stocked ponds, agricultural products are given at a rate of 7,000 kg/ha and animal products at 2,000 kg/ha.

In Hong Kong, polyculture ponds are heavily fertilized with green manure, animal manure, and chemical fertilizers for maintenance of natural food and adequate production. Supplementary feeds include green fodder, vegetable wastes, aquatic plants, rice bran, peanut cake, soybean cake, sesame cake, and wheat bran (Ling 1967).

Feeds and feeding methods in polyculture systems in Malaysia and Singapore are similar to those used in China, Taiwan, and Hong Kong, except that more animal manure is used. In Thailand, however, feeds used for Chinese carp culture are mainly of plant origin (Ling 1967).

7.7 *Disease and Parasite Control*

Diseases and the causative agents reported to infect bighead carp are discussed in sections 3.2.4 and 3.3.5. Parasites are controlled and diseases prevented by rigorous pond maintenance and disinfection (section 7.5.1). It is also recommended that larval fishes be kept separate from spawners (Bauer et al. 1973). Under natural spawning conditions, larvae are generally allowed to remain with the parents for 10 to 12 d; however, during this time, many disease-causing agents may be transmitted to the larvae. This transmission can be alleviated by artificially incubating the eggs in hatchery devices and stocking fry in nursery ponds.

Bighead carp fry infected with protozoan parasites may be effectively treated by using a 2.5% sodium chloride solution for 10–15 min (Molnar 1971). For underyearling and adult bighead carp, the control and treatment of protozoan parasites are more specific. *Cryptobia branchialis* is controlled in China by treating fish with 0.001% chloride of lime and 0.0008% copper sulfate for 15 to 30 min before the fish are put into culture ponds (Bauer et al. 1973). Species of *Eimeria* are controlled by disinfecting the pond with chloride of lime, and systematically drying and allowing the pond bottom to freeze to kill any oocysts present. *Ichthyophthirius* may be controlled in a similar manner; however, infected fish can be treated with malachite green. A concentration of 0.25 to 0.5 g/m^3 at 12° to 20 °C for 5 h is sufficient for adults, but underyearlings only should be treated with 0.2 to 0.25 g/m^3 for 3 h. Trichodiniasis, caused by several species of infusoria, can be controlled with salt or ammonia baths or by using sodium chloride in the pond.

Diseases caused by the trematode larvae of *Diplostomum* and *Posthodiplostomum* may be prevented by controlling the intermediate host, a snail. The snail can be controlled by drying and freezing the pond, using chemicals such as copper sulfate or chloride of lime, or introducing fish to feed on the snails (Bauer et al. 1973; FAO 1979). Diseases caused by *Dactylogyrus* sp. can be effectively treated by using ammonia baths or chemical preparations such as copper amine or Dipterex (Sarig et al. 1965; Bauer et al. 1973).

Cestode parasites can be controlled by disinfecting the ponds; however, since the mature parasites inhabit the intestines of birds, perhaps the best prevention of diseases caused by *Ligula* and *Diagramma* is to repel fish-eating birds from the pond site.

Lernaea sp. has been effectively treated with potassium permanganate, Dipterex, or Bromex-50 (Bauer et al. 1973; Chen 1976; Ji 1976; Anon. 1978; FAO 1979). *Synergasilus lieni* is a species specific parasite, infecting only bighead carp and silver carp. Therefore, a good preventive measure against introductions of this species is to avoid importing bighead carp from ponds where *Synergasilus* has been a problem. Copper and iron sulfate at a 5:2 ratio are used for treatment (Bauer et al. 1973).

Fungal infections caused by *Saprolegnia* sp. may be treated with malachite green, methylene blue, formalin,

copper sulfate, or potassium permanganate (Bauer et al. 1973; Chen 1976; FAO 1979).

Bacterial infections of bighead carp caused by *Pseudomonas dermoalba* have been successfully treated with a solution of mercurous acetate or mercurous nitrate (2 mg/L) 2 to 5 h at water temperatures below 15 °C, and for 2.5 h at higher temperatures. Aureomycin is also effective (Bauer et al. 1973).

7.8 *Production*

The productivity of aquaculture systems in China is high. Tapiador et al. (1977) reported target values for production used in national planning as 1,500 kg/ha in North China and 3,750 kg/ha south of the Yantze River. Intensive methods used in delta fish farms along the Pearl River resulted in annual yields of up to 18,000 kg/ha.

There are two types of aquaculture practices in China: multi-grade and mixed-age fish culture (Anon. 1978; FAO 1979). In multi-grade fish culture, fingerlings to marketable size fish are reared in a series of ponds and sorted according to size. This method allows for maximum growth potential since densities of fish can be adjusted according to their size and the productivity of the pond. An example of bighead carp culture in which this method was used is outlined in Table 14. Mixed-age culture is the traditional method of rearing different sized fishes together in the same pond, from fingerlings to marketable size. For example, bighead carp are released into the pond three times per year, at an interval of 3 to 6 mo, so that three sizes of fingerlings are reared in the pond at the same time. This method fully utilizes the pond area and increases total production.

Polyculture is practiced more commonly than monoculture in China, because the natural productivity of a pond can be fully used by mixing a proper combination of different species. In China, the four major carp species (bighead carp, grass carp, silver carp, and black carp) are generally used in combination with other species such as common carp, mud carp, goldfish (*Carassius auratus*), bream (*Abramis brama*), and *Tilapia* (Rabanal 1968; Tapiador et al. 1977). Stocking combinations vary according to the major species raised, which depends on their behavior and food preference, pond productivity, ecological conditions, and materials available for rearing. The

Table 14. *An example of multigrade culture of bighead carp (Anon. 1978).*

1. Storage pond	
Size	Reared from 0.01 kg to 0.03 kg
Average density	7,600–90,000 fish/ha
Area ratio	1.5%
Duration	1 yr
2. Small fingerling pond	
Size	Reared from 0.01 to 0.03 kg to 0.04 to 0.09 kg
Average density	6,000 fish/ha
Area ratio	3.6%
Duration	About 40 d
3. Medium sized fingerling pond	
Size	Reared from 0.04 to 0.09 kg to 0.2 to 0.25 kg
Average density	2,400 fish/ha
Area ratio	8.9%
Duration	About 40 d
4. Large sized fingerling pond	
Size	Reared from 0.2 to 0.25 kg to 0.5 kg
Average density	1,000 fish/ha
Area ratio	20.5%
Duration	About 40 d
5. Fattening pond	
Size	Reared from 0.5 kg to 1 to 1.5 kg
Average density	300 fish/ha
Area ratio	65%
Duration	About 40 d

bighead carp generally is not used as the major species in Chinese polyculture. In ponds where grass carp is the main species grown, the combination is usually 55% grass carp, 16% silver carp, 10% bighead carp, and 19% other, for stocking densities of 15,000 fish/ha (Anon. 1977; FAO 1979).

In northern China, bighead carp are stocked at higher densities in deeper ponds (3–7 m) because more emphasis is placed on plankton feeders (Table 15,A). In the West River drainage of South China and North Vietnam, bighead carp play a minor role compared with that of certain other species such as the mud carp, which can withstand moderately high temperatures (Table 15,B).

To insure normal growth of bighead carp in polyculture, it is recommended that the stocking density of silver carp be reduced to 300–455 kg/ha, or that fewer silver carp be raised between June and September, when the bighead carp grows most rapidly (Anon. 1978). This procedure will alleviate potential competition for phytoplankton.

The bighead carp is also used in river fish farming in China (FAO 1979). One example is the Tiensha River in Guangdong Province, where the Tang Sha People's Commune collectively cultivates the fish. The use of natural dry season pools along the river edges are used to rear fry to fingerlings. Fingerlings are stocked in the river by the flooding of the pools during the rainy season. An example of the stocking density used for a total water area of 90,000 ha follows: bighead carp 130,000; silver carp 50,000; grass carp 140,000; and common carp 80,000.

In lakes and reservoirs in China, where management is less intensive, the bighead carp is one of the major species stocked (Anon. 1977; Tapiador et al. 1977; FAO 1979). In Lake Taihu (225,000 ha), the annual production of bighead carp (the main species stocked) combined with bream totaled 12,000 tons in 1977, for an average yield of 53 fish/ha (FAO 1979).

In polyculture in the Soviet Union, the common carp is used in combination with the bighead carp, grass carp, and silver carp. These fish can be raised together in ponds formerly used for monoculture of common carp. Without providing additional feed, polyculture increases production by 400 to 600 kg/ha in central Russia, and 60 to 1,000 kg/ha in the south. Intensive feeding and pond fertilization increases production by 3,000 to 4,000 kg/ha (Vinogradov 1968; Anon. 1970). When bighead carp are combined with silver carp in the southern Soviet Union, bighead carp are stocked at an average rate of 500 to 700 fish/ha and at a ratio of silver carp to bighead carp of 4.5:1 or 1:1. When bighead carp are reared for market in the Soviet Union, the average weight of a 2-yr-old fish must be no less than 800 to 1,000 g in the southern zone. In the middle zone, however 2-yr-old bighead carp are acceptable at 300 to 400 g, but at 3 yr the average weight is 700 to 1,000 g (Anon. 1970). In the natural waters of the Soviet Union, a substantial increase in the productivity and yield of bighead carp has resulted from the creation of self-reproducing stocks of bighead in the basin of the Amu-Darya River (Aliev 1976). Annual production of bighead carp was only 8,200 kg in 1967–69, but increased to 5 million kg in 1973 and 1974.

Pond culture in Malaysia is similar to that in China. Bighead carp are combined with common carp, grass carp, silver carp, mud carp, and lampam jawa, *Puntius gonionotus* (Ji 1976; Table 15,C).

In Hong Kong, the bighead carp is used in polyculture with other Chinese carps and striped mullet (Table 15,D). Sin and Chiu (1987) stocked silver carp, bighead carp, grass carp, and common carp at a ratio of 7:5:5:6 and a total density of 3,000 fish/ha in two oxidation ponds at a sewage treatment plant. Bighead carp grew at rates comparable to or higher than those in commercial ponds. The daily weight increment averaged 5.2–7.7 g/d in warm weather and 0.7 g/d during cold weather. Overall growth was best in the pond receiving a mixture of effluents from the biological filter and activated sludge, which contained higher concentrations of phosphate and chlorophyll a. The net yield was 552 kg/ha.

Species combinations used in polyculture in Taiwan depend on water quality. Bighead carp are generally used with silver carp, common carp, and tilapia in eutrophic ponds, particularly when the farming of ducks or hogs with the fish is practiced (Chen 1976). Table 15,E, provides an example of species combinations used in central and southern Taiwan.

In Hungary, the bighead carp is now the most popular fish used in pond farming practice, and is the second most important culture species behind common carp. Average annual production of bighead carp reaches 2,600 metric tons (Pinter 1980).

Results from studies in Poland indicate that bighead carp are more productive than silver carp when stocked at the same densities; however, bighead carp may cause a decrease in common carp production due to competition for food (Opuszynski 1981). When 1,500 bighead carp/ha (36 g/fish) were combined with 2,000 common carp/ha (54 g/fish), total production was 261 kg/ha for bighead carp and 873 kg/ha for common carp. When compared to control ponds stocked with common carp only, the production of common carp was decreased by 228 kg/ha, yet total production was increased by 33 kg/ha. When bighead carp, silver carp, and grass carp (each stocked at 1,500 fish/ha) were combined with common carp stocked at 2,000/ha, bighead carp production was 186/kg/ha. Common carp production was reduced by 324 kg/ha, but total production increased 122 kg/ha over the control.

In the United States, the bighead carp has been used in polyculture production systems with silver carp, common carp, and grass carp and in combination with *Tilapia* sp., channel catfish, largemouth bass, and bigmouth buffalo (*Ictiobus cyprinellus*).

Henderson (1979) found that a combined polyculture system of bighead carp, silver carp, and channel catfish in Arkansas (Table 15,F) resulted in the same yield of channel catfish as in monoculture systems, and water quality of the ponds was improved. Newton et al. (1978), who compared a low-density polyculture system (bighead carp, silver carp, grass carp, largemouth bass, and channel catfish) to a channel catfish monoculture system, reported significantly greater net production from the polyculture ponds (Table 15,F). In a study to evaluate Chinese carp production methods for recycling swine manure, Buck et al. (1978b) combined bighead carp, silver carp, common carp, and grass carp with largemouth bass, channel catfish, and hybrid buffalo (bigmouth buffalo × black buffalo) in ponds receiving a constant supply of swine manure from pens placed directly above the ponds (Table 15,F). After 173 d, bighead carp gained an average of 6.5 to 6.9 g/d. The total biomass gained was 429–439 kg/ha, an average of 2.48–2.54 kg/ha per day. Henderson (1978) stocked 12,764 silver carp fingerlings/ha and 255 bighead fingerlings/ha, in a sewage treatment lagoon. After 16 mo, bighead carp production totaled 175 kg/ha; the average weight of the fish was 726.4 g.

7.9 *Harvest and Transport*

7.9.1 Harvest

In traditional culture of mixed-age fish, bighead carp are generally harvested three times a year. Fingerlings stocked in September of the previous years are cropped three times within 50 d, starting in June. Those stocked from February to March of the same year are cropped three times starting in August, and fingerlings stocked in June are cropped starting in October (Anon. 1978). The fish are harvested by gradually lowering the pond and using a seine or cast net, or by using dividing fish traps installed in the outlet structure to capture and aid in sorting the fish (Anon. 1970; Bardach et al. 1972; Tapiador et al. 1977; Green and Smitherman 1984). In polyculture ponds, the fish must be sorted to species. When the pond is lowered gradually, the species separate naturally. Bighead carp and silver carp concentrate at the surface; the bighead carp ascending after the silver carp. Grass carp and black carp concentrate at the bottom, and are the last to ascend (Lin 1949; Dah-Shu 1957; Vinogradov 1979).

7.9.2 Transportation

One of the most commonly used materials for transporting bighead carp is the hermetically sealed polyethylene bag, filled with water and oxygen in equal proportions. Density of fry placed in each bag depends on the length of transport. For shipments lasting up to 5 h, 100,000 larvae can be placed in a 40-L bag. Up to 50,000 fry can be placed in a 40-L bag for transportation between 5–24 h (Anon. 1970; Vinogradov 1979). Chen (1976) suggested that a bag 40 × 30 × 120 cm (144 L) can hold 500 fingerlings 7 cm long, 1,000 fingerlings 5 cm long, or 8,000 to 10,000 fry 2.5 cm long in 10 L of water for less than 10 h.

Before transport, the fish should be conditioned to crowding to reduce injury and mortality, and given no food so their guts will be empty (Chen 1976). Adults should be transported in well-oxygenated water (5 to 8 mg/L) at the lowest feasible temperature. At a temperature of 1 ° to 6 °C, the fish are semidormant, but above 10 °C they become very excitable. If fish must be transported at high temperatures, anesthesia may be used. Bardach et al. (1972) recommended 6.7 to 7.7 μg/L solution of sodium barbital or 1 to 4 g/L solution of urethane as effective at temperatures of 25.5 ° to 32 °C.

8. UTILITY

Henderson (1978, 1983) evaluated the potential of bighead carp and silver carp in improving the water quality of a sewage treatment lagoon in Arkansas. Results indicated that these fish have the ability to effect plankton removal, stimulate nutrient uptake, and generally improve the treatment efficiency of a conventional lagoon system, while simultaneously providing an annual production of more than 7,200 kg of fish/ha to offset water treatment costs. He suggested that further investigation should be conducted for finding ways of using these fishes. Examples include using them as biological filters for general water quality enhancement and in water supply reservoirs where plankton produces taste and odor problems, and as an additional source of protein produced from an unused resource.

The desirability of bighead carp as a marketable food fish was evaluated in the United States (Crawford et al. 1978). Fish raised at Auburn University, Alabama, yielded wholesale prices (live weight basis) of $0.55 to $0.99/kg to fish wholesalers and $1.10/kg to other persons. The wholesale price of completely dressed fish at supermarkets was $1.65/kg. Retail prices ranged from $2.18 to $3.06/kg at supermarkets and $3.04 to $5.26/kg from fish wholesalers. The bighead carp was marketed under the names "fish," "carp," "speckled amur," and "Chinese bass." Results from supermarket sales indicated that bighead carp weighing 3.6 to 5.4 kg could be successfully marketed at retail.

In Arkansas, marketability tests revealed that the palatability of bighead carp flesh was comparable to or better than that of channel catfish or bigmouth buffalo (Henderson 1976). The bighead carp has potential value in the United States as either a food fish for human consumption, for use in organic fertilizer or as a fish meal by-product. The market value for this fish could be profitable for any of the described uses because production costs are low.

Table 15. *Example of stocking combinations of bighead carp used in polyculture (% of total).*

A. Northern China (Bardach et al. 1972).

<table>
<tr><th rowspan="2">Pond Size</th><th colspan="7">Species</th><th rowspan="2">Total #/ha</th></tr>
<tr><th>Bighead</th><th>Silver</th><th>Grass</th><th></th><th>Black</th><th>Common</th><th>Bream</th></tr>
<tr><td>2–3 m deep</td><td>8%</td><td>41%</td><td>–</td><td></td><td>41%</td><td>3%</td><td>7%</td><td>7,300</td></tr>
<tr><td>2–3 m deep</td><td>17%</td><td>32%</td><td>21%</td><td></td><td>23%</td><td>2%</td><td>5%</td><td>9,500</td></tr>
<tr><td>3–7 m deep</td><td colspan="2">85%</td><td>3%</td><td></td><td>–</td><td>4%</td><td>–</td><td>5,300</td></tr>
<tr><td>3–7 m deep</td><td colspan="2">74%</td><td>24%</td><td>or</td><td>24%</td><td>2%</td><td>–</td><td>12,200</td></tr>
</table>

B. West River Valleys of China and North Vietnam (Bardach et al. 1972; Lin 1954).

Pond size	Species							Total #/ha
	Bighead	Silver	Grass	Black	Mud	Common	Bream	
1.5 m deep	6%	6%	24.5%	2%	37%	24.5%	–	4,900
1.5 m deep	3.5%	3.5%	17.5%	0.3%	70%	5.2%	–	6,864
2 m deep	10%	23%	9%	1%	46%	–	11	5,250
2 m deep	4%	4%	22%	1%	66%	3%	–	10,850

C. Malaysia (Lin 1954; Ji 1976; Bardach et al. 1972).

Bighead	Silver	Grass	Common	Total #/ha
15.5%	15.5%	46.5%	22.5%	645
16%	18%	44%	22%	1,125
10%	10%	60%	20%	1,250
23%	12%	6%	59%	2,125

Table 15. *Continued.*

D. Hong Kong (Lin 1954; Bardach et al. 1972).

Bighead	Silver	Grass	Mud	Common	Striped	Total #/ha
6%	8%	6%	35%	–	45%	26,868
2%	2%	2%	29%	16%	49%	30,700

E. Central and South Taiwan (Chen 1976).

Bighead	Silver	Grass	Mud	Common	Mullet	Crucian	Walking catfish	Snakehead	Total #/ha
2%	16%	1%	20%	20%	40%	–	–	–	4,950
4%	10%	2%	15%	20%	20%	20%	5%	5%	10,100

F. United States (Buck et al. 1978b; Newton et al. 1978; Henderson 1979).

State	Bighead	Silver	Grass	Common	Largemouth bass	Channel catfish	Buffalo hybrid	Total #/ha
Arkansas	2.5%	9.5%	–	–	–	88%	–	5,174
	6%	6%	–	–	–	88%	–	8,203
	5.5%	26.5%	1%	–	1%	66%	–	4,750
Illinois	4%	48%	1%	17%	1%	1%	28%	10,341

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16. Abstract (Limit: 200 words)

The bighead carp is recognized throughout the world because of its versatility in aquaculture operations. Although endemic to eastern China, it has been introduced throughout the world as an important food fish. It has also been use with other fish to improve water quality and to increase fish production, both in culture and natural systems. This literature summary follows the Food and Agricultural Organization of the United Nations (FAO) species synopsis format.

17. Document Analysis a. Descriptors

Bighead carp, Hypophthalmichthys nobilis, Cyprinidae, aquaculture, exotic, food fish, water quality

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